EPA-SW-82TS-71

PB 197 931

SATELLITE VEHICLE SYSTEMS FOR SOLID WASTE COLLECTION

Evaluation and Application

This study was made by the

Division of Technical Operations

and its report (SW-82ts) was written by RONALD A. PERKINS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Solid Waste Management Office
1971

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253

BIBLIOGRAPHIC DATA SHEET

1. Report No. EPA-SW-82TS-71

2.

3. Recipient's Accession No.

4. Title and Subtitle
Satellite Vehicle Systems for Solid Waste Collection; Evaluation and Application

5. Report Date 1971

6.

7. Author(s)
Ronald A. Perkins

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
U.S. Environmental Protection Agency
Solid Waste Management Office
Cincinnati, Ohio 45213

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address
U.S. Environmental Protection Agency
Solid Waste Management Office
Rockville, Maryland 20852

13. Type of Report & Period Covered

14.

15. Supplementary Notes

COLOR ILLUSTRATIONS REPRODUCED IN BLACK AND WHITE

16. Abstracts

The productive efficiency and costs associated with residential satellite vehicle collection systems are quantitatively evaluated and compared with conventional collection systems for collecting residential solid waste. Those factors that affect efficiency and economy were quantitatively analyzed to develop models that can predict collection cost and crew efficiency with a high degree of accuracy and provide a practical and reliable basis for designing future collection systems using satellite vehicles. Four makes of satellite vehicles (Cushman, Trashmobile, Westcoaster, and Trash Taxi) operating in six communities with diverse terrain, type of collection agency, and collection frequency were chosen for the study. These small three- or four-wheeled vehicles transport wastes from the dwelling unit storage point to a packer truck for ultimate transfer to a disposal site. The vehicles reportedly work best in areas with single-family homes where housing density is medium to low. The costs, which could not be compared because they occurred under distinctively different conditions, are measured as "annual cost per dwelling" rather than as "cost per ton."

17. Key Words and Document Analysis. 17a. Descriptors

*Refuse disposal, *Collection, *Ground vehicles, Bulk transporter, *Systems analysis, Mathematical models, *Cost comparison

17b. Identifiers/Open-Ended Terms

*Solid waste disposal, *Waste collectors, Cushman, Trashmobile, Westcoaster, Trash Taxi, *Solid waste collection system, *Satellite vehicle waste collection, Mini motor truck, Residneital density, Atlanta (Georgia), Columbia (South Carolina), Knoxville (Tennessee), Medford (Oregon), Pasadena (California), Waukesha County (Wisconsin)

17c. COSATI Field/Group 13B

18. Availability Statement
Release to public

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages 253

22. Price $3 or $0.95

FORM NTIS-35 (10-70)

USCOMM-DC 40329-P71

ENVIRONMENTAL PROTECTION AGENCY
Solid Waste Management Office
Cincinnati, OH 45213

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INFORMATION SERVICE

March 23, 1971

Our Reference: SWMO, OI, #479

Input Section
National Technical Information
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FOREWORD

Current solid waste collection practices do not differ significantly from those used at the turn of the century. The horse-drawn cart has merely been replaced by a motor-powered van that has a larger capacity and a compaction capability. This lag in the development of new technologies has had a marked economic impact, because it costs four times as much to collect residential solid wastes as it does to dispose of them. Ways must be found, therefore, to maximize efficiency while minimizing costs.

Thus, an in-depth study was made of a new collection system in which small "satellite" vehicles are used. The present report is the result and presents operational details of the system and compares it with conventional walking pick up. The relative efficiencies achieved by private and municipal operators are also outlined. Finally, the report postulates that a community can use the mathematical models developed by the study to estimate the efficiency and cost of such a system for its area, thus avoiding expensive field studies and trial implementation.

--RICHARD D. VAUGHAN
Assistant Surgeon General
Acting Commissioner
Solid Waste Management Office

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SATELLITE VEHICLE SYSTEMS FOR SOLID WASTE COLLECTION

SUMMARY AND CONCLUSIONS

General

The use of satellite vehicles for collection of residential solid wastes can be an efficient and economical alternative to the conventional collection systems currently in use when the wastes must be collected at the house.

The efficiency and cost of a potential satellite vehicle waste collection system can be accurately approximated without costly field studies or experimental implementation by a community investigating alternative collection systems, by using the collection models developed in this report.

System Design and Application

The efficiency, which this study defines as the total number of dwelling units a crew is able to service per unit of time, can be determined by the satellite vehicle operator and packer truck driver collection models developed in this study. Usage of these models depends upon knowledge of the effects of collection frequency per week, housing density and lot size upon the variables which determine productive collection time required to service a given number of dwelling units. The model which describes the time required to complete one round trip with the satellite vehicle is:

$$Y_T = \frac{0.80X_1 + 0.13X_2 + 0.007X_3 + 0.086X_4 + 3.45X_5 - 0.78 + U}{E_s}$$

where Y_T = the total time, in minutes, to complete one satellite vehicle round trip, servicing X_1 dwelling units

X_1 = the total number of dwelling units serviced in one round trip

X_2 = the total number of containers and other distinct and separate items of waste material collected from X_1 dwelling units

X_3 = the average distance, in feet, which the satellite vehicle is able to drive up each dwelling unit driveway

X_4 = the average distance, in feet, which the satellite vehicle operator must walk from his satellite vehicle to the waste storage location at each dwelling unit

X_5 = the total route distance of the satellite vehicle round trip, in miles

U = the unloading time of the satellite vehicle at the packer truck, in minutes

E_s = the fraction of the satellite vehicle operator's total time on the collection route which is occupied by driving, collecting, and unloading activities

The packer truck driver collection model is:

$$T = 0.60b_1 + 0.31b_2 + 0.011b_3 - 0.60$$

where T = the total time, in minutes, to service b_1 dwelling units between truck moves

b_1 = total number of dwelling units serviced by the packer truck driver between truck moves

b_2 = total number of items collected from b_1 dwelling units

b_3 = the average distance, in feet, from the packer truck to the waste storage location at each dwelling unit

The selection of proper values for each of the variables in the collection models is explained in this report.

The expected cost of a satellite vehicle system, expressed as annual collection cost per dwelling unit, can be accurately estimated using the crew efficiency and the expected crew costs. The satellite vehicle collection cost estimation model is:

$$C = \frac{ZC_L \div C_T + (Z-1)C_s + C_o}{H} \left[\frac{1}{\dfrac{60X_1(Z-1)}{Y_T} + \dfrac{60b_1B_D}{T}} \right] (N)$$

where C = annual collection cost per dwelling unit

Z = total number of men in crew

C_L = labor cost in dollars per man per day

C_T = packer truck operation, depreciation and maintenance costs, in dollars per day

C_S = satellite vehicle depreciation, operation and maintenance costs, in dollars per day

C_o = overhead cost of crew, in dollars per day

H = total number of hours per day which the crew spends on the collection route. This time does not include driving times to and from the route, to and from the disposal site, formal break times, or lunch time

Y_T = total time, in minutes, to complete one satellite vehicle round trip

X_1 = total number of dwelling units serviced in one satellite vehicle round trip

T = total time, in minutes, required by the packer truck driver to service b_1 dwelling units between truck moves

b_1 = total number of dwelling units serviced by the packer truck driver between truck moves

E_D = the fraction of the packer driver's total time on the collection route, H, which he devotes to collection

N = the number of collections which the dwelling unit receives in 1 year

The values for C_T and C_s are discussed in the report, while values for C_L and C_o are different for each particular community.

System Capabilities

The satellite vehicles serviced an average of 5 dwelling units per load in areas with once-weekly collection and 10 dwelling units per load in areas with twice-weekly collection (p 61).

Satellite vehicle operators collected an average of 15 items per load for both once and twice-weekly collection (p 41).

The mean satellite vehicle route distance was 0.45 miles per load for once-weekly collection and 0.75 miles per load for twice-weekly collection (p 47).

The average time required to unload a satellite vehicle was 1.5 min per load or 11 percent of the total trip time (Table 7).

The time required to service the average dwelling unit (Table 2) on once-weekly collection by satellite vehicle was 2.11 min. The time required to service the average dwelling unit on twice-weekly collection was 1.84 min per collection or a total of 3.68 min per week (p 62).

Collection in hilly areas required 15 percent more time than collection of dwelling units with similar characteristics in flat areas due to the reduced speed of the satellite vehicles imposed by steep roads and driveways (p 68).

Satellite vehicle operators were able to service more dwelling units per hour than hypothetical walking collection crews under identical conditions, in five of the six sites studied (Table 22).

Crew Activity Analysis

Values for E_s for individual satellite vehicle operators ranged from 0.764 to 1.000 with a mean of 0.950 (Appendices).

Every crew observed worked under the incentive system and the average value for H was 6.0 hr per day (p 91).

Packer truck drivers devoted only 16.1 percent of their time to driving and were able to participate in collection 30.2 percent of their total time on the route (Table 18).

Packer truck drivers spent 16.0 percent of their time assisting the satellite vehicle unloading process (Table 18).

Items Collected per Dwelling Unit

Dwelling units receiving twice-weekly collection averaged 1.6 items when garden wastes were not included (Table 8).

Dwelling units receiving once-weekly collection averaged 2.3 items per collection when garden wastes were not included. Inclusion of garden wastes increased the items collected per dwelling unit by 40 to 100 percent (Table 8).

System Costs

Satellite vehicle operation, maintenance and depreciation costs accounted for 11 percent of the total cost of a 3-man crew with two satellite vehicles (p 87).

Labor wages and fringe benefits accounted for 60 percent of the total cost of a 3-man crew with two satellite vehicles (p 86).

For identical conditions (p. 89) the average cost for once-weekly collection was $19.00 per dwelling unit per year and $10.00 per ton collected (Table 21).

For identical conditions (p. 89) the average cost for twice-weekly collection was $28.50 per dwelling unit per year and $15.00 per ton collected (Table 21).

Comparison of Private and Municipal Systems

The average private satellite vehicle operator was able to service the standard dwelling unit 22 percent faster than the average public satellite vehicle operator (Table 12).

Packer truck drivers in private crews deveoted an average of 59.0 percent of their time to collection. Municipal packer truck drivers used only 1.4 percent of their time to collect (Table 18).

For identical conditions the cost of collection to municipal agencies averaged 53 percent more per dwelling unit and per ton than that to private collection, due to the higher efficiency of the private satellite vehicle operator and the participation in collection by the private packer truck driver (Table 21). It must be remembered that this does not refer to the cost to the resident but to the collection agency. Cost to the resident would be higher because management costs are not considered in this report.

Qualitative Evaluation of Satellite Vehicle Systems

Satellite vehicle system users reported increased morale, lower absenteeism, and fewer injury claims due to the reduced physical work required of waste collectors using satellite vehicles.

Homeowners receiving satellite vehicle waste collection regarded its use as a technological advance by the collection agent and this improved the homeowners' image of the waste collector.

Satellite vehicle usage resulted in littering of streets in some of the areas in which they were observed.

Satellite vehicles were excessively noisy in several instances.

Satellite vehicle users reported high maintenance costs and short useful lives due to the lightweight construction of these vehicles.

Satellite vehicle users reported several instances of satellite vehicles overturning when subjected to sharp turns.

Operational Recommendations

The selection of the appropriate packer truck to provide maximum operating efficiency in conjunction with the satellite vehicles is extremely important. The packer should have a hopper of 2 cu yd or greater to accommodate the satellite vehicle load in one cycle of the packer. Slight equipment modifications may be necessary to provide maximum coordination between the satellite vehicle hopper and the packer blade during unloading, and to minimize spillage of wastes.

Packer trucks should be radio-equipped for communication with the garage or central office to inform collectors of missed dwelling units or extra pick-ups. This contact will also minimize down time due to packer or satellite vehicle breakdowns.

Satellite vehicles should be equipped to facilitate waste transfer to the packer with a minimum amount of spillage. Rubber or canvas flaps attached to the rear lip of the satellite vehicle hopper and welded metal wings on the sides of the hopper at the rear will ease the flow of wastes from the satellite vehicle hopper into the packer hopper.

Satellite vehicles should not be loaded above the top of the hopper. Overloading results in waste spillage enroute to the packer and impedes the unloading operation. The vehicle should be driven slowly enough to prevent paper from blowing out of the hopper.

Safety of the satellite vehicle operators should be a prime consideration. Visible turning signals, large rearview mirrors, safety reflectors and extra taillights should be standard equipment on all satellite vehicles.

Coordination between satellite vehicle operators and the packer truck drivers working in one crew is necessary for optimum crew efficiency. The operators can avoid duplication of service by establishing a set pattern to be followed each time that a particular route is covered. The satellite vehicles should work close enough to the packer truck to minimize haul distances and avoid losing the packer truck. The packer truck driver should participate in collection, but should also be available at the truck to assist in the satellite vehicle unloading operation.

A means of transferring wastes from the dwelling unit storage point to the satellite vehicle should be available. Each satellite vehicle operator should have a 40- to 60-gal lightweight, manageable container with his vehicle to eliminate carrying homeowners' containers back and forth to the vehicle.

Satellite vehicles should be on strict preventive maintenance programs to extend their useful life and minimize mechanical failures during their operation. The lightweight construction and small engines of the vehicles are subjected to rough usage, necessitating such a program.

Establishment of good customer relations can be extremely beneficial to the satellite vehicle operators. Thoughtful homeowners will remove obstacles which reduce satellite vehicle accessibility to the waste storage point.

Customer containerization of their wastes in paper or plastic bags improves the handling of the wastes by the collector and prevents loose articles from falling from the satellite vehicles when in motion.

INTRODUCTION

Since the inception of the Bureau of Solid Waste Management in 1965 much research time and monies have been devoted to the development of new and improved methods for disposal of solid wastes. Despite the fact that collection and transfer comprises 80 percent of the total cost of solid waste handling, there has been very little encouragement for new collection technology on the national level. As a result, current residential solid waste collection practices do not differ significantly from those used at the turn of the century. The one-horse open cart has simply been replaced by a multiple horsepowered enclosed van with greater capacity.

Residential solid wastes are collected from many different locations, depending in large measure on the existence of suitable alleys and on the amount of money available for the collection service. The collection point may be located at the curb, in an alley, on the back porch, in the backyard, at the front or back house lot lines, in basements and even inside houses. When the collection point is anywhere except at the curb or in an alley, the collection system is said to be a "backyard" collection system. Backyard collection is the most convenient and costly system to the homeowner and is used in approximately one-third of all communities in the United States.[1] To maintain this convenience for the homeowner a means of maximizing efficiency and minimizing costs must be sought.

One new method currently being used in approximately 50 communities with backyard residential collection is satellite collection vehicles. These are small, manually operated, three or four wheeled vehicles which transport wastes from the dwelling unit storage point to a packer truck for ultimate transfer to a disposal site (Figures 1 and 2). These vehicles have capacities of 1 to 3 cu yd and weigh 1200 to 2600 lb. The hoppers are equipped with hydraulic lifts to transfer wastes from the vehicle to the packer truck. The vehicles reportedly work best in areas with single-family homes where housing density is medium to low.

With publicity focused on solid waste disposal research, this new concept of residential solid waste collection has not received warranted recognition and publicity. Several municipalities and private collectors reported decreased costs and increased collection efficiency using satellite vehicle systems. Since residential collection costs are four times the cost of disposal, any opportunity to decrease collection costs cannot be neglected.

This study was initiated with the objective of quantitatively evaluating the productive efficiency and costs associated with residential satellite vehicle collection systems. Quantitative analysis of those factors in the collection process

Figure 1. Loading a satellite vehicle

Figure 2. Unloading satellite vehicle at packer truck

which effect the efficiency and economy of the system would be undertaken to provide a practical and reliable basis for designing future collection systems using satellite vehicles. To allow comprehensive investigation of these factors, four makes of satellite vehicles operating in a wide range of conditions were chosen for the study. The four satellite vehicles studied were the Cushman, the Trashmobile, the Westcoaster, and the Trash Taxi (Figures 3-6). Six systems were chosen for the study based on their diversity in vehicle type, terrain, collection agency and collection frequency (Table 1).

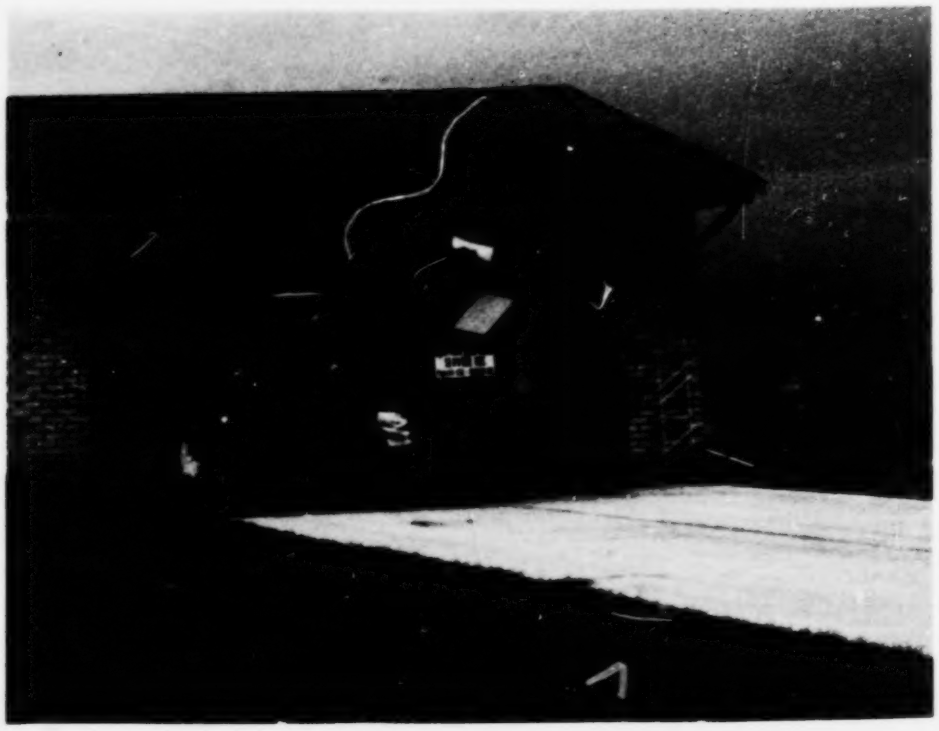

Figure 3. Cushman waste collection vehicle

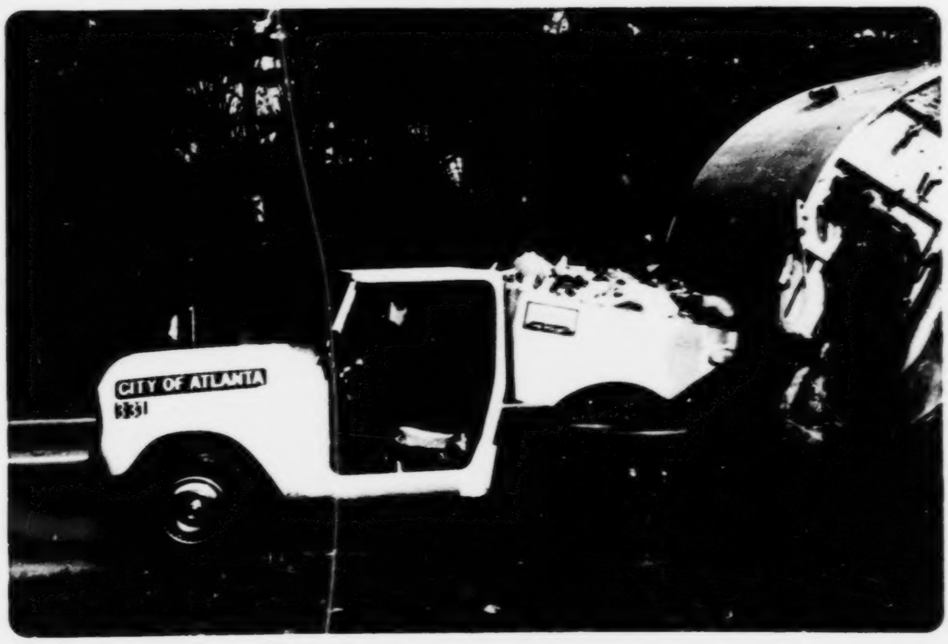
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Figure 4. Trashmobile waste collection vehicle

Figure 5. Westcoaster waste collection vehicle

Figure 6. Trash Taxi waste collection vehicle

TABLE 1

DESCRIPTION OF SATELLITE VEHICLE WASTE COLLECTION SYSTEM STUDY SITES

Study site and date	Collection responsibility	Type of satellite vehicle	Collection frequency	Terrain
Atlanta, Georgia August 18-22, 1969	municipal	Trash Taxi and Trashmobile	twice/week	hilly
Columbia, South Carolina June 24-27, 1969	municipal	Cushman	twice/week	flat
Knoxville, Tennessee July 14-18, 1969	private	Trashmobile	once/week	hilly
Medford, Oregon August 4-8, 1969	private	Cushman	once/week and twice/week	flat
Pasadena, California July 28-August 1, 1969	municipal	Westcoaster	once/week	hilly and flat
Waukasha County, Wisconsin July 8-11, 1969	private	Cushman	once/week	flat

STUDY PROCEDURE

Prior to the initiation of the actual study, two pilot studies were conducted in the greater Cincinnati, Ohio area. These studies were conducted to test collection time study procedures which had been previously developed by the Bureau for the Territory of Guam.[2] These time study procedures were altered significantly to correspond with the operations peculiar to satellite waste collection vehicle systems. During these studies it became obvious that there was little correlation between weight of solid waste collected and time required for collection. Collectors took longer to collect three containers with 10 lb of waste in each than they did to collect one container with 30 lb of waste.

Based on this observation, it was decided that the number of items collected and the number of dwelling units serviced would provide higher correlations with collection time. Correspondingly, since the object of waste collection is to service the most dwelling units in the least amount of time at the lowest cost, it was decided that annual cost per dwelling unit would be more practical and meaningful than the traditional cost per ton. The author of this report strongly believes in this concept and thus cost per dwelling unit is the ultimate measure of cost used throughout the investigation.

The evaluation of the six satellite vehicle systems was conducted in two distinct phases; the first phase was the determination of system costs; the second phase consisted of 1-week-long studies of satellite vehicle operations at each site.

Phase One - Cost Study

Meetings were held with the owners of the private collection companies and with the superintendents of the municipal collection systems studies to obtain the costs associated with their satellite waste collection vehicle systems. The associated costs obtained were crew hourly wages and fringe benefits; satellite vehicle depreciation, maintenance and operating costs; packer truck depreciation, maintenance and operating costs; and the overhead required for the system. Overhead costs were not generally known by the collection agent and therefore a factor of 20 percent of all other costs was assumed for the collection system cost computations and analyses. This assumption is based upon known overhead percentages from other collection systems with accurate accounting procedures.

Adequate collection system cost data were readily available in all of the study areas with the exception of Knoxville, Tennessee. Collection system cost calculations for Knoxville were based on cost estimates from the Trashmobile manufacturer's literature.

Phase Two - Field Evaluation

Comprehensive field evaluations of satellite vehicle collection systems were conducted to determine the effect of selected factors on the efficiency of the system. The field evaluation at each study site was 4 to 5 days in length. At least one collection crew using satellite vehicles was studied at each study site. The study team accompanied the collection crew during their entire work day to account for any efficiency variation due to fatigue at the end of the day.

Three-man study teams were used on all of the field evaluations. This allowed accompaniment and observation of two satellite vehicles and the packer truck. The activities of the satellite vehicle operators and the packer truck driver were timed and recorded in detail.

Motorcycles were used by the study team members to maintain a close contact with the satellite vehicle operators at all times. These members were equipped with stopwatches and clip boards to facilitate data collection (Figure 7). The third member followed the packer truck in a car and was equipped with several stopwatches to record all other necessary times (Figure 8).

Collection Time Study Work Sheets. The "Collection Time Study Work Sheet" was used by the study team to record the necessary data associated with the activities of the satellite vehicle operators (Figure 9). Each sheet corresponded to one round trip by a satellite vehicle to and from the packer truck. A discussion

Figure 7. Satellite vehicle data collection procedure

Figure 8. Recording data on packer truck driver

Figure 9

COLLECTION TIME STUDY WORK SHEET

COLLECTOR________________________ DATE ______________

END ODOMETER READING____________ ELAPSED TIME______________

BEGIN ODOMETER READING__________ UNLOADING TIME______________

TOTAL DISTANCE__________________ OTHER TIME________________

PRODUCTIVE COLLECTION TIME ____________

SERVICE	NUMBER OF ITEMS	DISTANCES (feet)			ACCOMPANIED
		STREET TO STORAGE	SCOOTER UP DRIVEWAY	SCOOTER TO STORAGE	
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
ALS					
AVERAGES					

DATA BY____________________

of each item on the work sheet will familiarize the reader with the factors evaluated and the method of recording them.

Collector - the name of the satellite vehicle operator being observed

End odometer reading - the reading on the motorcycle odometer when the satellite vehicle returns to the packer truck to unload

Begin odometer reading - the reading on the motorcycle odometer when the satellite vehicle leaves the packer truck to begin a round trip

Total distance - the difference between "end odometer reading" and "begin odometer reading", in miles

Date - the month and day on which the data were recorded

Elapsed time - the total time which elapses from the time that the satellite vehicle leaves the packer truck until the time that it has returned to the truck and unloaded. This is the time of the satellite vehicle round trip cycle. Time was recorded to the nearest 0.1 min. This time was recorded by the study team member following the packer truck.

Unloading time - the time required for the satellite vehicle to empty its entire load into the packer truck. The time starts when the satellite vehicle arrives at the packer truck. The time ends when the satellite vehicle hopper is emptied and lowered to its original position.

Unloading time and other time are subtracted from elapsed time to yield productive time per load.

Other time - the time spent on activities which do not contribute constructively to the process of waste collection. Some examples are:

1) talking to homeowner
2) getting a drink of water
3) receiving instructions from the packer truck driver
4) picking up roadside litter
5) waiting for homeowner to open garage door
6) lighting and smoking a cigarette
7) salvaging
8) other miscellaneous activities not part of the actual collection process

Formal break times normally allowed to the crews are not considered as "other time", but are accounted for in the ensuing analyses.

Productive collection time - total elapsed time per satellite vehicle round trip minus unloading and other time

Service - a solid waste storage location. One service can include the wastes from any number of dwelling units. An apartment building with four families which has one storage location is one service, but four dwelling units. The number of dwelling units was recorded in parentheses when there was more than one per service.

Number of items - the total number of standard solid waste containers, other containers and distinct pieces of wastes collected by the satellite vehicle operator at each service. This variable was sometimes broken down to measure the effect of garden wastes and particular types of containers.

Street to storage distance - the estimated perpendicular distance in feet, from the edge of the street to the point of waste storage for each service. This distance was estimated to the nearest 10 ft by the study team.

Scooter up driveway distance - the estimated distance which the satellite vehicle traveled on each dwelling unit property. This distance was estimated to the nearest 10 ft by the study team.

Scooter to storage - the estimated distance which the operator walked from his satellite vehicle to the point of waste storage at each service. This distance was estimated to the nearest 10 ft by the study team.

Accompanied - this column was checked if the study team member on motorcycle accompanied the satellite vehicle from the edge of the street to the point where it stopped at the service. If checked, the corresponding "scooter up driveway distance" was doubled and subtracted from "total distance" to yield the actual route distance that the satellite vehicle traveled along the road during each round trip.

Data by - the name or initials of the Bureau member who recorded the data

In addition, each work sheet was numbered to record the order in which they occurred. The work sheet was given to the member of the study team following the packer truck by the data recorder on motorcycle, each time the satellite vehicle returned to the packer truck (Figure 10). The elapsed time for the satellite vehicle round trip was recorded when the satellite vehicle had completely unloaded.

Driver Collection Time Data Sheet. The "Driver Collection Time Data Sheet" was used to record the activities of the packer truck driver (Figure 11). Only one or two sheets were necessary to record all of the driver's activities each day. In addition, the sheet was used to record general collection crew information required for the study. Each item on this form will be discussed to illustrate its purpose.

Date - the month and day on which the data were recorded
City - the name of the community where the study was being conducted
Pickup point - the location of waste storage at collection time, for the crew being studied. The pickup point was classified as backyard in all the situations encountered during the study.

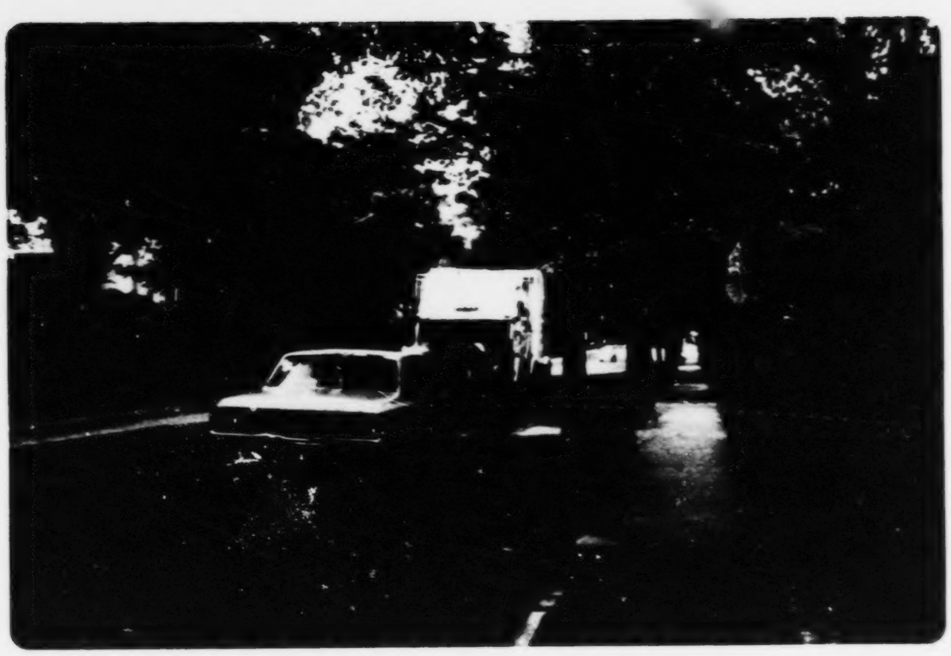

Figure 10. Transferring data sheet at packer truck

Figure 11

DRIVER COLLECTION TIME DATA SHEET

DATE__________ VEHICLE NO.__________ CREW SIZE__________

CITY__________ TYPE__________ TOTAL SERVICES__________

PICKUP POINT__________ CAPACITY__________ TOTAL ITEMS__________

DATA BY__________

BEGIN ODOMETER READING__________ ASSISTANCE TIME__________

END ODOMETER READING__________ WAITING TIME__________

TOTAL DISTANCE__________ OTHER TIME__________

TOTAL COLLECTION TIME__________

SERVICES	NUMBER OF ITEMS	DISTANCE ST. TO STOR.	ELAPSED TIME	SERVICES	NUMBER OF ITEMS	DISTANCE ST. TO STOR.	ELAPSED TIME

Vehicle no. - the identification number of the packer truck being observed

Type - the make of the packer truck body

Capacity - the size of the packer truck in cubic yards

Crew size - number of satellite vehicle operators, walking collectors and the packer truck driver

Total items - the total number of containerized and uncontainerized waste articles collected by the packer truck driver

Data by - the name or initials of the Bureau member following the packer truck

Begin odometer reading - the odometer reading of the car following the packer truck, recorded when the packer truck reached the first stop on the collection route. The odometer readings were taken to the nearest 0.05 mile.

End odometer reading - the odometer reading of the car at the last stop before going to the disposal site or any other destination off route.

Total distance - the difference between begin and end odometer readings. This is the route mileage of the packer truck.

Total collection time - the total number of minutes that the packer truck is on the collection route. This is the time between the first and last stops which the packer truck makes on the collection route. Formal break times are not included.

Assistance time - the time which the packer truck driver spends in assisting the satellite vehicle operators in unloading wastes into the packer truck and instructing the operators in their collection activity.

Waiting time - the time in minutes which the packer truck driver spends standing or sitting at the packer truck, waiting for the return of the satellite vehicles. This is non-productive time for the driver.

Other time - the time in minutes which the packer truck driver spends on any activity which prevents him from being available to assist the satellite vehicle operators upon their return. A list of common activities is given in "other time" for satellite vehicle operators.

Services - the number of solid waste storage locations serviced by the packer truck driver between truck moves.

Number of items - the total number of distinct containerized and uncontainerized articles of waste collected by the packer truck driver between truck moves.

Distance street to storage - the average distance in feet, which the packer truck driver walked from the truck to the waste storage point for each service collected between truck moves.

Elapsed time - the total collection time required by the packer truck driver to collect the number of services given on the same line, in minutes.

FIELD STUDY DATA ANALYSIS

A total of 1050 satellite vehicle loads and 592 packer driver trips were observed and recorded during the field studies. The data obtained were subjected to standard statistical analyses and extensive multiple regression analyses. The primary objective of the data analyses was to determine the effects of selected measurable factors upon satellite vehicle collection crew efficiency. Accurate establishment of these effects could then provide a sound basis for the design of future satellite vehicle collection systems.

The study results were based upon observations of twenty-six satellite vehicle operators and twelve packer truck drivers working in six distinct areas of the country.

Satellite Vehicle Operational Analysis

Individual stepwise regression analyses were performed on the data from each satellite vehicle operator observed. These results are presented and analyzed in the individual Appendices for each study site. Analyses were also performed on the total data obtained at each study site (Table 2). These analyses yielded equations which described the productive collection time required for each satellite vehicle load. The productive collection time, Y_p, was best described by the following variables:

TABLE 2
AVERAGE VALUES FOR SATELLITE VEHICLE COLLECTION VARIABLES BY STUDY SITE

Study site	Satellite vehicle loads observed	Variable						
		X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway (ft)	X_4 Distance vehicle to storage (ft)	X_5 Route distance per load (mile)	D_{ss} Distance street to storage (ft)	Y_P Productive time per load (min)
Atlanta, Georgia								
Trash Taxi	104	8	16	100	30	0.35	130	15.1
Trashmobile	21	12	19	70	30	0.80	90	16.0
Columbia, South Carolina	46	11	21	50	30	1.55	80	22.6
Knoxville, Tennessee	287	6	15	100	20	0.55	110	9.7
Medford, Oregon	82	10	12	90	20	0.80	110	11.6
Pasadena, California								
Hills	132	3	10	120	10	0.50	110	7.9
Flat	205	3	10	100	0	0.15	100	4.1
Waukesha County, Wisconsin	173	5	22	70	10	0.60	70	7.7
All sites combined	1,050	6	15	90	10	0.50	100	9.4

X_1, the total number of dwelling units serviced during one round trip of the satellite vehicle; X_2, the total number of items collected from X_1 dwelling units; X_3, the average distance, in feet, which the satellite vehicle is able to drive on each dwelling unit property; X_4, the average distance, in feet, which the satellite vehicle operator must walk from his satellite vehicle to the storage point of each dwelling unit; and X_5, the total route distance, in miles, which the satellite vehicle travels during the round trip. The values of these variables depend upon collection frequency, housing density and lot size in the area to be collected. Thus a community can design a satellite vehicle collection system without expensive field studies or trial implementation, simply by knowing the effects of these three factors upon the five variables which determine productive collection time required for a satellite vehicle load.

A regression analysis of these same five variables against the productive collection time for all 1,050 satellite vehicle loads observed during the study was performed. The resultant equation was:

$$Y_P = 0.80X_1 + 0.13X_2 + 0.007X_3 + 0.086X_4 + 3.45X_5 - 0.78 \quad (1)$$

This model was able to explain 81.5 percent of the total variation in the data, and the standard deviation of the residuals was 27.1 percent of the response mean, productive collection time. The model coefficient values of the five variables were very similar to those for the individual study sites (Table 3),

TABLE 3

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS BY STUDY SITE

Study site	Variable						R_2 Percent variation explained
	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway	X_4 Distance vehicle to storage	X_5 Route distance per load	X_0 Constant term	
Atlanta, Georgia							
Trash Taxi	*1.06	0.25	0.019	0.047	4.81	-2.69	87.7
Trashmobile	0.39	0.14	0.021	0.058	*4.99	1.40	91.6
Columbia, South Carolina	*1.10	--	--	--	3.02	5.42	71.7
Knoxville, Tennessee	*0.77	0.16	0.002	0.039	1.75	0.57	70.4
Medford, Oregon	0.40	*0.42	0.010	0.094	3.50	-3.02	80.7
Pasadena, California	*0.63	0.20	0.073	0.107	5.04	-1.22	84.5
Waukesha County, Wisconsin	0.54	0.15	0.011	0.047	*2.93	-0.89	83.0
All sites combined	*0.80	0.13	0.007	0.086	3.45	-0.78	81.5

*Variable most highly correlated with productive time.

despite the dissimilarities in operating conditions at each site. The correlation coefficients between variables illustrates their independence (Table 4).

The confidence to be placed upon the use of the regression model presented above is dependent upon the quality, quantity and distribution (Table 3) of the variables which are the basis of its development. The fact that the model covered 81.5 percent of the total variation in the input data and that the F value was 922.1, is a significant indication of its accuracy and quality. The quantity and distribution of the input data becomes obvious in the analyses of the regression model variables and other factors which effect satellite vehicle collection system efficiency.

Regression Model Analysis. The regression model consists of five variables which accurately describe the productive collection time required per satellite vehicle load. A discussion of each of these variables will illustrate their significance and will indicate the values to be used for design purposes.

X_1, Dwelling Units Per Satellite Vehicle Load. The number of dwelling units serviced in a satellite vehicle load was the most significant variable in describing Y_P, the productive time required per satellite vehicle load. Since the satellite vehicle has a fixed capacity, X_1 increases as the number of items per dwelling unit decreases. Therefore, X_1 is highly dependent upon collection frequency, since items per dwelling unit per collection increase as the number of collections per week decreases.

TABLE 4

CORRELATION COEFFICIENTS OF SATELLITE VEHICLE COLLECTION MODEL VARIABLES

Variable	Variable				
	X_1	X_2	X_3	X_4	X_5
X_1	1.000	0.518	0.489	-0.186	0.407
X_2	0.518	1.000	0.393	-0.179	0.056
X_3	0.489	0.393	1.000	-0.008	0.135
X_4	-0.186	-0.179	-0.008	1.000	-0.112
X_5	0.407	0.056	0.135	-0.112	1.000

The satellite vehicle hopper capacities observed ranged from 1.25 to 1.50 cu yd. This limited range did not allow any direct correlation between number of items per load and hopper capacity.

There is a high correlation between collection frequency and number of dwelling units serviced per load. For once per week collection the satellite vehicles collected an average of 4.53 dwelling units and 14.42 items per load. Where twice per week collection was in effect, the satellite vehicles collected an average of 9.78 dwelling units and 16.10 items per load.

For design purposes the value of X_1 is determined by the formula:

$$X_1 = \frac{15}{\text{average items per dwelling unit}}$$

The number of dwelling units per load is also dependent upon the types of wastes which the collection agent is responsible for collecting. Where crews are required to collect garden wastes with household wastes, the number of items per dwelling unit increases as much as 100 percent, and thus the number of dwelling units per load is reduced significantly. Many communities designate garden wastes as "trash" and collect it separately.

The average number of dwelling units serviced per satellite vehicle load was 5.71 and the coefficient of X_1 was 0.80 (Table 5). The wide distribution of observed values for X_1 lends statistical validity to the coefficient value determined by the regression analysis (Figure 12).

TABLE 5

STATISTICAL INFORMATION
REGRESSION MODEL VARIABLES

Variable	Correlation coefficient with Y_P	Coefficient and 95 percent confidence interval	Mean value	Range
X_1	0.818	0.80 ± 0.06	5.71	1-25
X_2	0.538	0.13 ± 0.027	14.8	1-43
X_3	-0.064	0.0067 ± 0.0022	92.7 ft	0-3000 ft
X_4	0.483	0.086 ± 0.011	14.7 ft	0-300 ft
X_5	0.661	3.45 ± 0.30	0.50 miles	0.0-4.7 miles

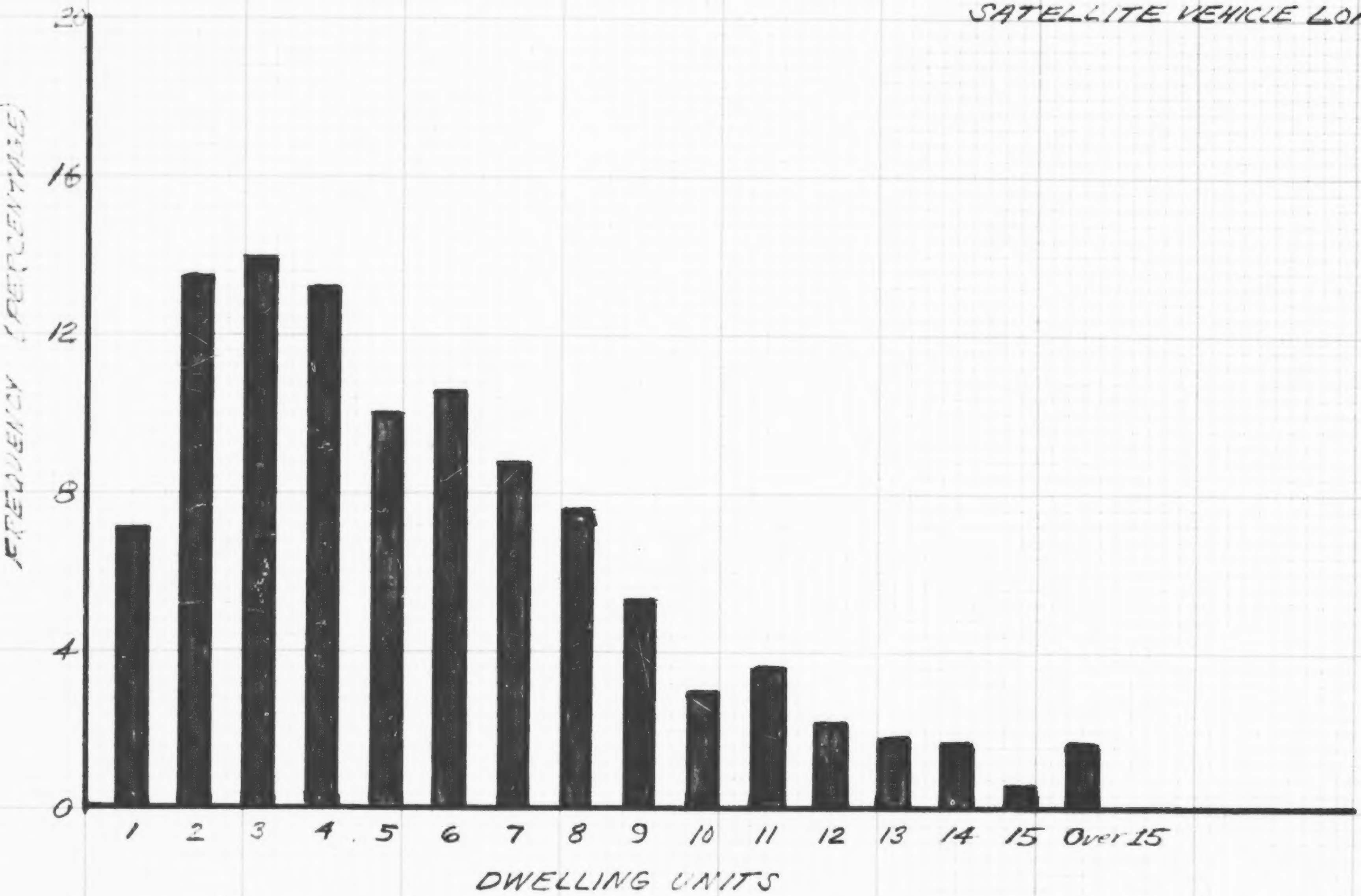

FIGURE 12
DISTRIBUTION
DWELLING UNITS
PER
SATELLITE VEHICLE LOAD

X_2, Items Per Satellite Vehicle Load. The number of items collected per satellite vehicle load was fourth in order of importance for describing productive collection time, Y_P. The correlation coefficient between productive time, Y_P, and X_2 was 0.538 for the 1,050 loads observed (Table 5).

X_2 is dependent upon the hopper capacity of the satellite vehicle and the size of the items collected. The satellite vehicles observed had an average capacity of 15 items per load.

The study observations included 2,310 dwelling units recving twice-weekly collection and 3,684 dwelling units receiving once-weekly collection. The mean number of items per satellite vehicle load was 14.80 and the coefficient of the variable, X_2, was 0.13 (Table 5).

X_3, Distance Satellite Vehicle Travels on Dwelling Unit Property. The average distance which the satellite vehicle traveled on a dwelling unit property was the least important of the five variables used to describe productive time required per satellite vehicle load. The correlation coefficient for X_3 and the productive time per load, Y_P, was -0.064 (Table 5). X_3 is dependent primarily upon dwelling unit lot size and waste storage location, and secondly upon homeowner habits and practices. The relationship between lot size, waste storage location and X_3 can be expressed as follows:

$$D_{SS} = 0.83X_3 + 0.76X_4 + 11.4 \qquad (2)$$

where D_{SS} = perpendicular distance from edge of street to waste storage location, in feet

X_3 = distance satellite vehicle travels on dwelling unit property, in feet

X_4 = distance from satellite vehicle to waste storage location, in feet

The relationship between homeowner habits and X_3 is called accessibility and is expressed as:

$$A = \frac{X_3}{X_3 + X_4} \qquad (3)$$

where A = accessibility, expressed as a fraction

D_{SS} and A may be estimated from a visual survey of the collection area. X_3 and X_4 can then be determined by simultaneous solution of these two equations.

Accessibility averages in the six study areas ranged from 0.727 to 1.000 (Table 6). Low accessibilities are indicative of obstructions in driveways, such as automobiles, or poor storage locations, which force the operator to leave his vehicle and walk to the storage area. Collection efficiency is reduced when wastes are stored in basements, at the rear of homes and at the bottom of stairways.

Five thousand, nine hundred and ninety-four individual satellite-vehicle-on-property distances contributed to the 1,050 average values per load for X_3. The mean value of X_3 was 92.7 ft and its coefficient was 0.0067 (Table 5).

TABLE 6

ACCESSIBILITY TO WASTE STORAGE LOCATION

Study site	Distance vehicle up driveway (X_3)	Distance traveled to storage $(X_3 + X_4)$	Accessibility $\left(\frac{X_3}{X_3 + X_4}\right)$
Atlanta	90	120	0.750
Columbia	80	110	0.727
Knoxville	100	120	0.833
Medford	90	110	0.818
Pasadena			
hilly	120	130	0.923
flat	100	100	1.000
Waukesha	70	80	0.875
All cities	90	110	0.818

The observed values for X_3 were well distributed from 0 to 150 ft and ranged from 0 to 3,000 ft (Figure 13). The value of X_3 was zero at 15.3 percent of the dwelling units serviced. This meant that the waste was located at the street or that some obstruction prevented the vehicle from entering upon the dwelling unit property. When either case occurs, the purpose of using satellite vehicles is defeated.

X_4, Average Distance from Satellite Vehicle to Storage. The average distance from the satellite vehicle to the waste storage location for the dwelling units serviced in one load was the third most important factor in describing the productive time required. The correlation coefficient for X_4 and Y_P, the productive time required per load, was 0.483 (Table 5). X_4 is dependent upon accessibility to the waste storage location and may be determined by simultaneous solution of equations (2) and (3) discussed previously. For a given dwelling unit, as X_4 increases accessibility approaches zero, and the satellite vehicle operator assumes a role similar to the conventional walking collector, since satellite vehicle usage, X_3, is minimized.

The values for X_4 ranged from 0 to 300 ft with a median of 10 ft (Figure 14). The optimum distance for greatest efficiency, 0 ft, occurred at 47.0 percent of the dwelling units observed.

The average values for X_4 in the six study areas ranged from 0 to 30 ft (Table 2), thus providing sufficient testing of the regression model over this range.

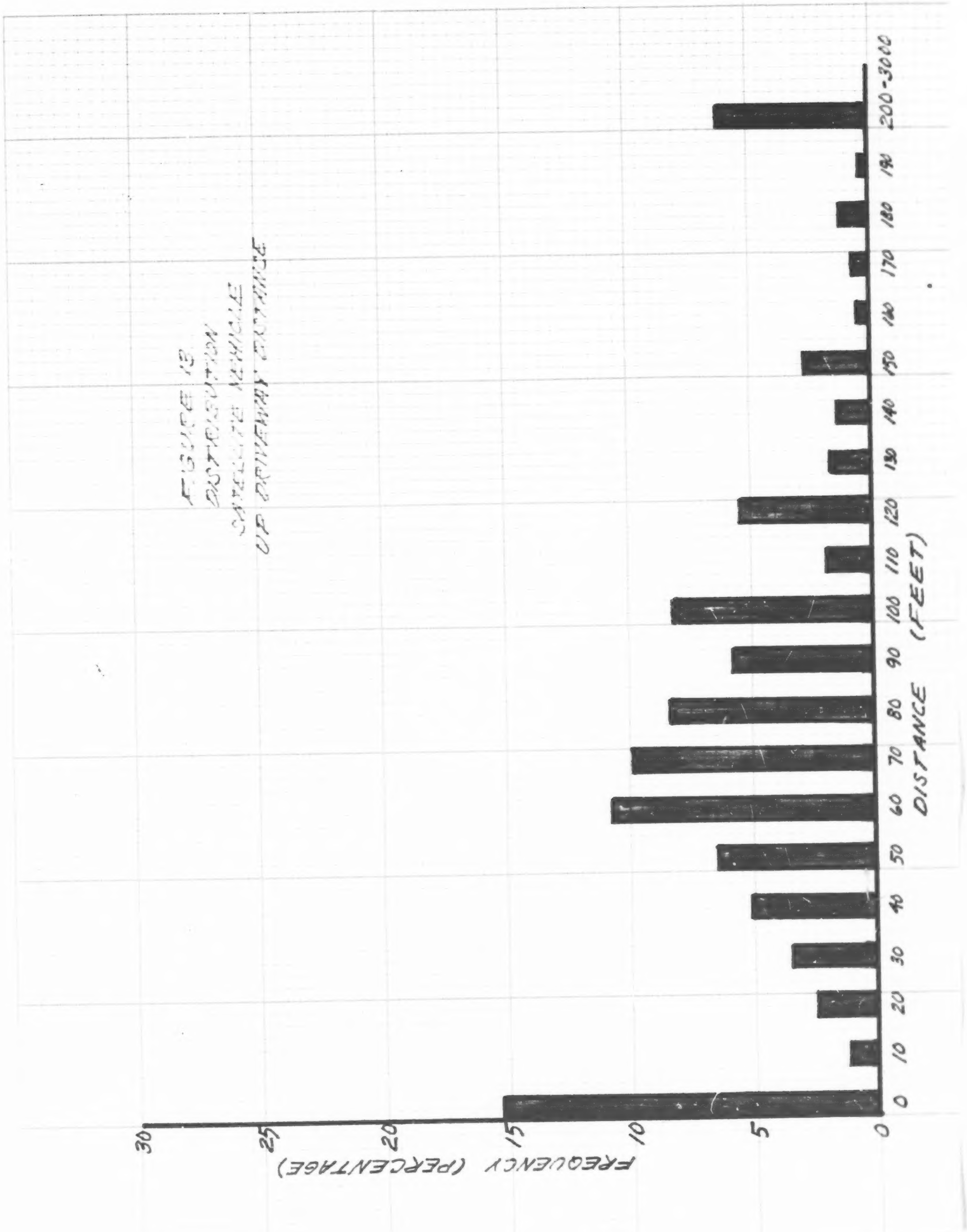

FIGURE 13
DISTRIBUTION
SATELLITE VEHICLE
UP DRIVEWAY DISTANCE

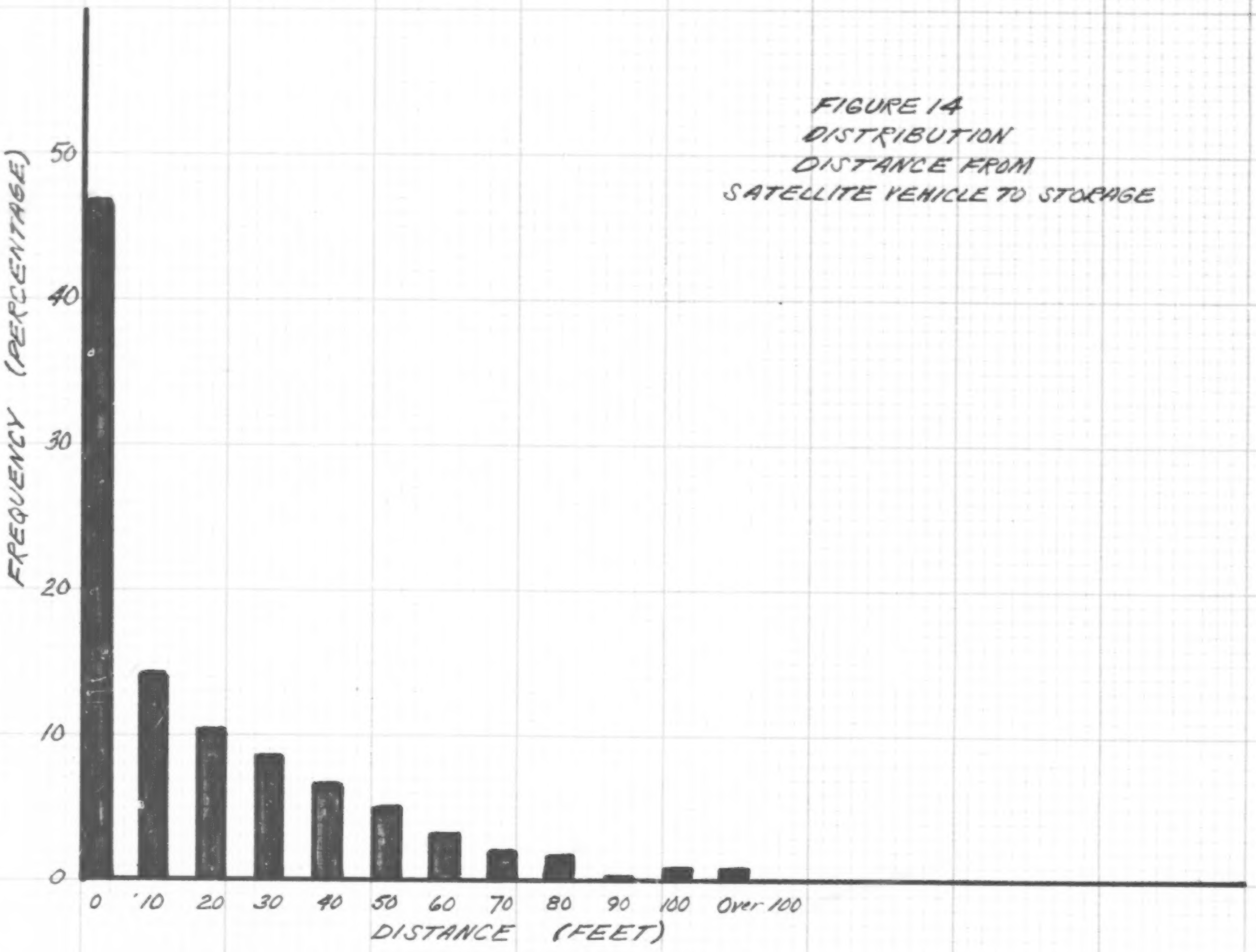

FIGURE 14
DISTRIBUTION
DISTANCE FROM
SATELLITE VEHICLE TO STORAGE

X_5, Satellite Vehicle Route Distance Per Load. Route distance per satellite vehicle load was the second most important factor in describing the productive time required. The correlation coefficient between X_5 and Y_P, the productive time required per load, was 0.661 (Table 5). The route distance is a function of housing density in the collection area, total number of dwelling units serviced, and the proximity of the satellite vehicle collection area to the packer truck.

X_5 can be estimated best by using the housing density of the collection area. A relationship between route distance per dwelling unit and housing density was developed from the study data by plotting housing density versus X_5 divided by X_1 at each site (Figure 15). Housing densities in the study areas ranged from 40 to 140 dwelling units per mile of street. The route distance per dwelling unit increases as housing density decreases.

For a given housing density the route distance logically increases as the number of dwelling units serviced per load increases. As stated earlier, the number of dwelling units per load is a function of collection frequency. The mean route distance for once-weekly collection areas was 0.45 miles per load, while the mean for twice-weekly collection was 0.75 miles per load.

The route distance can be kept at a minimum by operating the satellite vehicles as close to the packer truck as possible. If the average route distance of 0.50 miles per load was increased

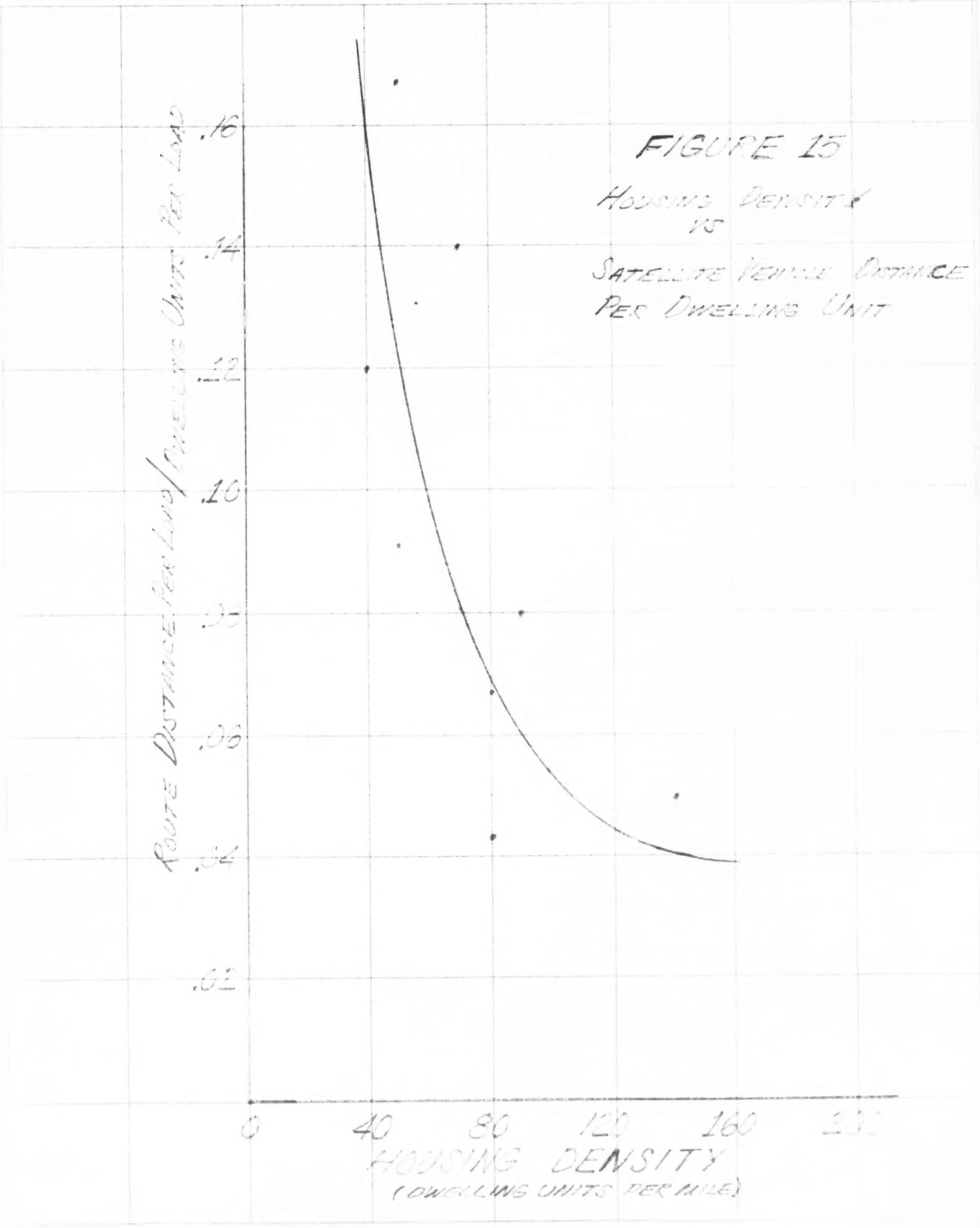

FIGURE 15

Housing Density vs Satellite Vehicle Distance Per Dwelling Unit

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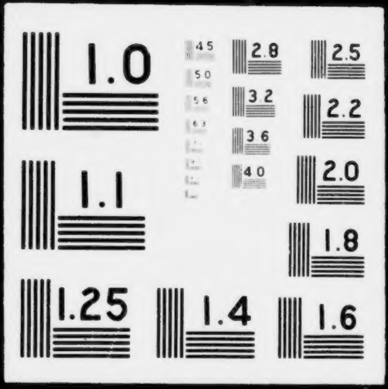
1.0
45
50
56
63
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

50 percent by not working close to the packer truck, the productive time required per average load would be increased by 0.86 min. This would cause a decrease in collection efficiency of approximately 10 percent.

Y_p, Productive Collection Time Per Satellite Vehicle Load. The productive collection time required for one satellite vehicle round trip is dependent upon the five variables discussed and the particular movements of each operator. It has been illustrated that the five variables in the model explain approximately 80 percent of the variation in productive time values, with a standard deviation of 27 percent. The remaining 20 percent of the variation is unexplainable because of particular movements peculiar to the individual operator.

The productive time per satellite vehicle load only includes that time which productively contributes to the collection process. The unloading time of the satellite vehicle and "other time" must be taken into account to obtain the actual total elapsed time per satellite vehicle round trip. These two factors are discussed in the Analysis of Other Variables section. Productive collection time accounted for approximately 84 percent of the total trip time for the average satellite vehicle operator (Table 7).

Analysis of Other Variables. In addition to the five variables included in the regression model there are other factors which must be taken into account before a total system may be

TABLE 7

SATELLITE VEHICLE ROUND TRIP TIME ANALYSIS

Study Site	Percent of total time per round trip		
	Productive	Unloading	Other
Atlanta, Georgia			
Trash Taxi	87.9	8.6	3.5
Trashmobile	92.2	7.0	0.8
Columbia, South Carolina	82.3	8.3	9.4
Knoxville, Tennessee	87.1	8.4	4.5
Medford, Oregon	82.2	11.4	6.4
Pasadena, California			
Central	80.2	14.9	4.8
West	82.3	13.7	4.0
Waukesha County, Wisconsin	77.5	16.6	5.9
Average for all sites	83.9	11.1	5.0

designed. The number of items per dwelling unit, distance from street to storage, unloading time and other time all contribute vital information and effect the five variables used in the collection model. A discussion and analysis of each of these factors will establish their significance in the satellite vehicle system design process.

Items Per Dwelling Unit. The number of items to be collected at one dwelling unit is a function of the collection frequency and the limitations on types of wastes which are to be collected by the collection agent. As collection frequency increases, the number of items per dwelling unit per collection decreases correspondingly. Where garden wastes are collected with household wastes the number of items per dwelling unit will be increased significantly.

The three study sites with once-weekly collection averaged 2.3 items per dwelling unit when garden wastes were not included and 3.9 when they were (Table 8). The three study sites with twice-weekly collection had separate collection of garden wastes and averaged 1.6 items per dwelling unit (Table 8). During the study, 2,310 dwelling units with twice-weekly collection and 3,684 dwelling units with once-weekly collection were observed. The distribution of items per dwelling unit illustrates significant differences when plotted by collection frequency (Figure 16). Two items per dwelling unit was the most common occurrence for once-weekly collection and 1 item per dwelling unit the most common occurrence for twice-weekly collection.

TABLE 8

AVERAGE NUMBER OF ITEMS PER DWELLING UNIT AT EACH STUDY SITE

Study Site	Collection frequency (per week)	Were garden wastes collected by satellite vehicle?	Average number of items per dwelling unit	
			With garden wastes	Without garden wastes
Atlanta, Georgia	2	No	-	1.8
Columbia, South Carolina	2	No	-	1.9
Knoxville, Tennessee	1	No	-	2.5
Medford, Oregon	2	No	-	1.2
Pasadena, California	1	Yes	3.3	2.3
Waukesha County, Wisconsin	1	Yes	4.4	2.2
Average for once-weekly collection	1		3.9	2.3
Average for twice-weekly collection	2		-	1.6

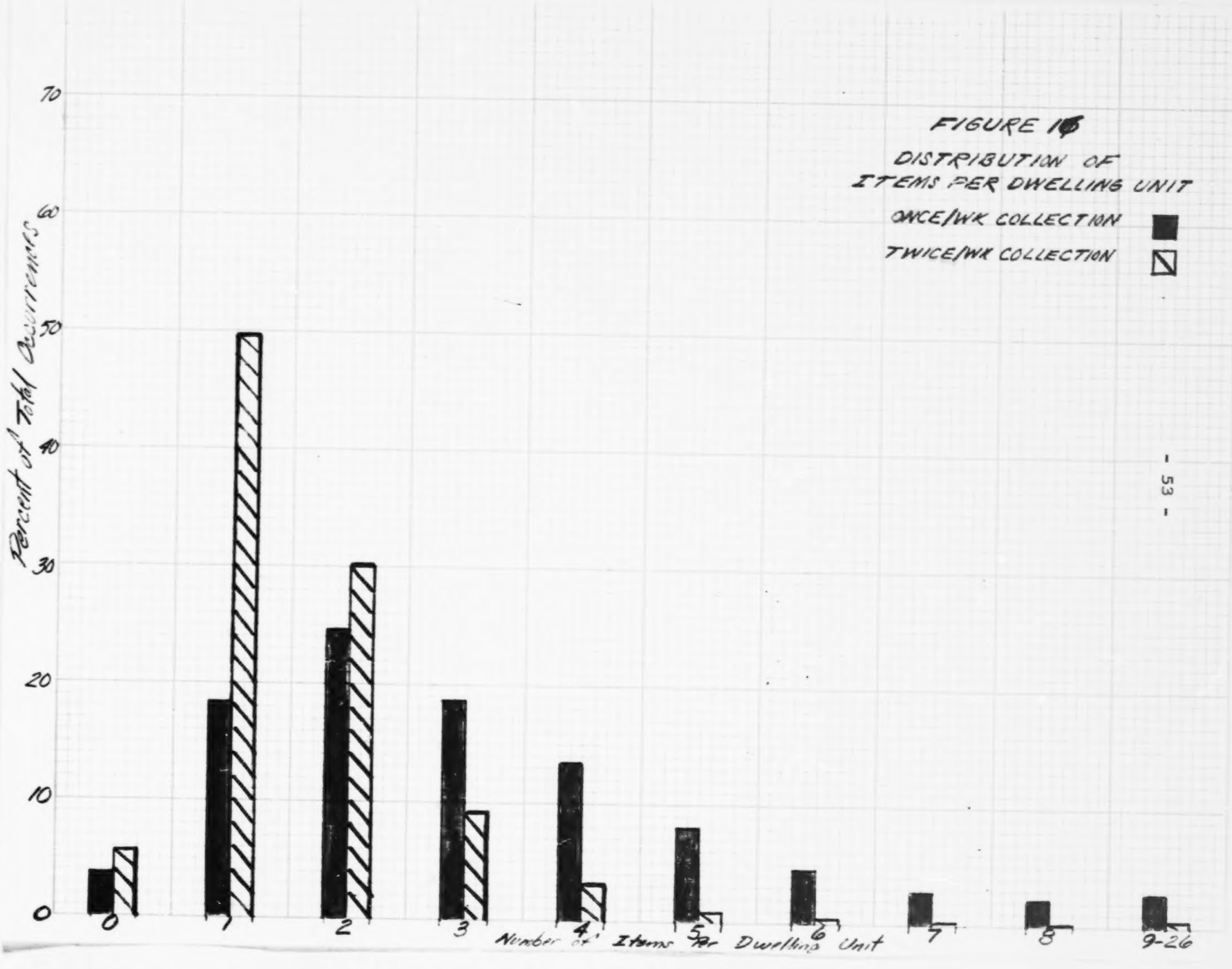

FIGURE 1Ø

DISTRIBUTION OF ITEMS PER DWELLING UNIT

Communities which allow garden wastes to be combined with household wastes can expect as much as a 100 percent increase in the number of items to be collected per dwelling unit (Table 8). Garden wastes accounted for 30 percent of the items collected in Pasadena and 50 percent of the items collected in Waukesha County.

Distance from Street to Storage. The perpendicular distance from the edge of the street to the waste storage location was recorded for each dwelling unit observed during the study. The distance from street to storage, D_{SS}, is used to determine X_3 and X_4 (p 41). D_{SS} may be estimated from visual observation of any collection area. It is dependent upon house lot size and customer practices.

The mean street to storage distance of the 5,994 dwelling units observed was 99.4 ft. The values for D_{SS} ranged from 0 to 3,000 ft with a median value of 80 ft (Figure 17).

Satellite Vehicle Unloading Time. The time required to transfer wastes from the satellite vehicle to the packer truck constituted approximately 11 percent of the total time that the satellite vehicle operators were observed (Table 7). Unloading time is dependent upon the satellite vehicle hopper loading practice and dumping mechanism, the hopper size and compaction cycle time of the packer truck, the amount of assistance provided by the packer truck driver and queuing at the packer truck (Table 9).

Satellite vehicles have several methods of unloading and may be used in conjunction with front, rear, or side-loading packers (Figures 18, 19, 20, 21). The four makes of vehicles studied

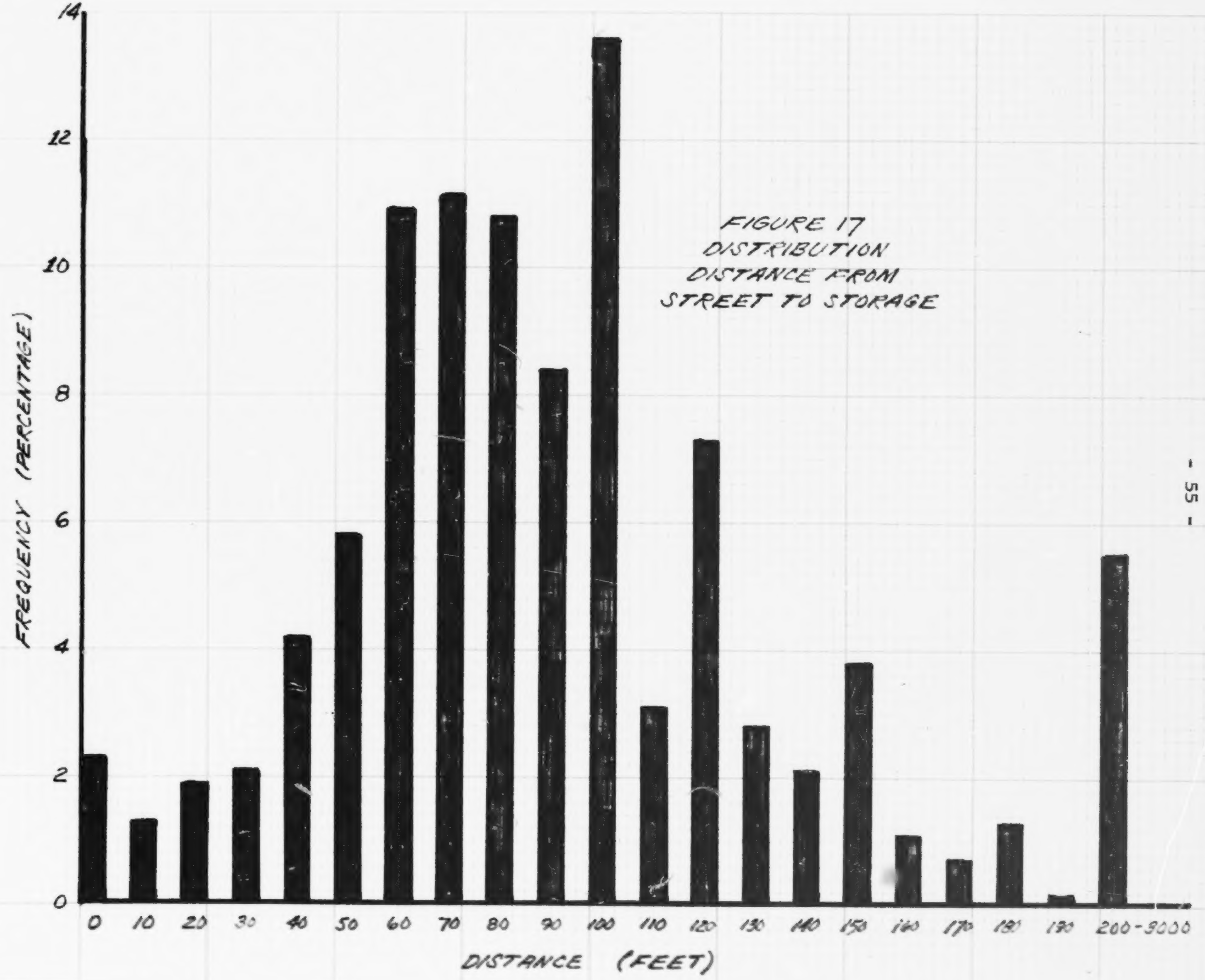
FIGURE 17
DISTRIBUTION
DISTANCE FROM
STREET TO STORAGE

TABLE 9

SATELLITE VEHICLE UNLOADING TIME FACTORS

Study site	Satellite vehicle	Items per load	Packer hopper size (yd^3)	Packer driver assistance	Unloading time (min)
Atlanta, Georgia	Trash Taxi	16	1.5	7%	1.5
	Trashmobile	19	1.5	7%	1.2
Columbia, South Carolina	Cushman (dump)	22	*	11%	2.5
	Cushman (flatbed)	19	1.5	0	2.1
Knoxville, Tennessee	Trashmobile	15	1.5	18%	0.9
Medford, Oregon	Cushman	12	1.5	13%	1.8
Pasadena, California	Westcoaster	10	3.0	43%	1.3
	Westcoaster	10	2.0	57%	0.8
Waukesha County, Wisconsin	Cushman	22	1.5	0%	1.7
Average for all sites		15	1.7	16%	1.5

*Side-loading packer without definite hopper capacity

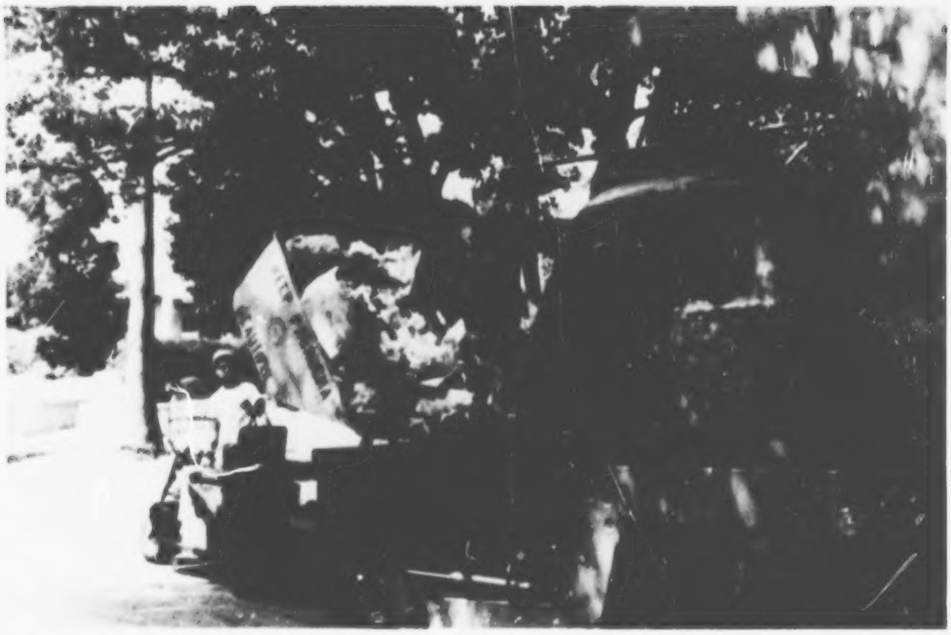

Figure 18. Unloading into front-loading packer truck

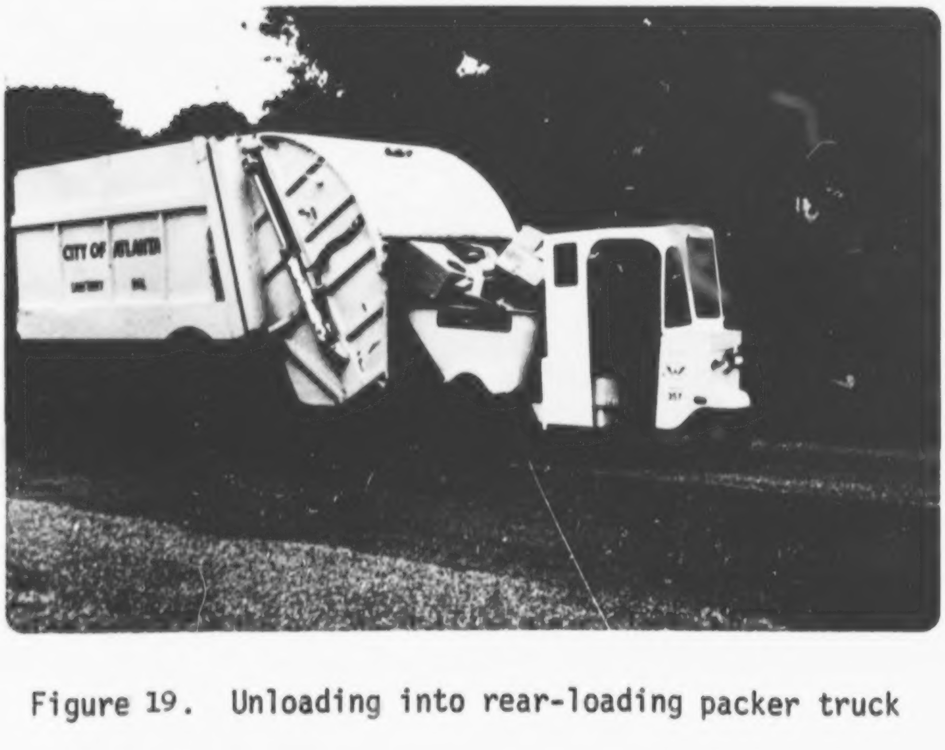
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Figure 19. Unloading into rear-loading packer truck

Figure 20. Unloading by hand into rear-loading packer truck

Figure 21. Unloading into side-loading packer truck

were equipped with hydraulic dumping mechanisms which had varying dump lifting times. Also a flat-bed unloaded manually was observed in Columbia, South Carolina.

Overloading the satellite vehicles with too many items resulted in an increased unloading time. Overloading required additional compaction cycles of the packer truck and a concerted effort by the operator to minimize waste spillage during the unloading process. In most cases 15 items were collected per load to maintain low unloading times. Columbia and Waukesha County crews required higher unloading times due to overloading (Table 9).

Unloading time is very much dependent upon the hopper capacity of the packer truck and the length of the compaction cycle. Trucks with hoppers smaller than 2 cu yd require two or more compaction cycles to accommodate the wastes from any satellite vehicle. The length of the compaction cycle becomes important when multiple compaction cycles are required. The packer trucks with 2 and 3 cu yd hoppers used in Pasadena, California were able to accept the wastes from the satellite vehicles in an average of 1.1 min, while trucks with smaller hoppers averaged 1.6 min unloading time.

The amount of time which the packer truck driver spends assisting the satellite vehicle operators during the unloading process is also important. Assistance from the packer driver allows the satellite vehicle operator to remain in his vehicle. The packer truck drivers remove waste stuck in the satellite vehicle hopper and clean up the area around the truck after the satellite vehicles have left. The drivers observed during the study assisted the satellite vehicle operators from 0 to 60 percent of their time. Assistance time of 20 percent of total time on the route would be adequate for a crew with two satellite vehicles. Queuing at the packer truck causes an increase in unloading time as satellite vehicles wait to be unloaded. Queuing could be easily eliminated for crews with only two satellite vehicles by proper coordination between the two operators. For three or more satellite vehicles per crew, some queuing is unavoidable but can be minimized by proper operational coordination. During the study, queuing occurred more frequently than appeared necessary under the circumstances. Operators used this waiting time for a brief rest between trips and an opportunity to talk with each other.

Following the operating procedures outlined above, it is estimated that all of the vehicles observed could unload in approximately 1 min if used in conjunction with a packer truck with a hopper of 2 cu yd or greater.

Adding unloading time to productive collecion time yields the total time required to complete one round trip with the satellite vehicle, assuming there is no "other time" involved.

$$Y_M = 0.80X_1 + 0.13X_2 + 0.007X_3 + 0.086X_4 + 3.45X_5 - 0.78 + U$$

where Y_M = minimum round trip time required to service X_1 dwelling units

U = satellite vehicle unloading time

Other Time. Inclusion of non-productive time or "other time" in the equation will yield the total time which any operator will require to complete one round trip with the satellite vehicle. This is expressed as:

$$Y_T = \frac{0.80X_1 + 0.13X_2 + 0.007X_3 + 0.086X_4 + 3.45X_5 - 0.78 + U}{E_S}$$

where E_S = the fraction of the satellite vehicle operator's total time which is occupied by collection and unloading activities

The average values of E_S for each study site ranged from 0.906 to 0.992 with a mean value of 0.950.

Effects of External Influences on Collection Efficiency

In addition to the variables which must be considered within a satellite vehicle system, there are outside influences which are not under the control of the satellite vehicle operator, and affect collection efficiency. The design of the investigation allowed effects of collection frequency, collection agency, satellite vehicle type, collection area terrain, type of item collected and weather conditions to be evaluated.

Collection Frequency. Increased collection frequency enables more dwelling units to be serviced per satellite vehicle load, due to the decreased number of items per dwelling unit. During the study, the satellite vehicles operating on once-weekly routes averaged 4.53 dwelling units per load while those on twice-weekly routes averaged 9.78 dwelling units per load. To service the average dwelling unit once-weekly requires 2.11 min. To service the average dwelling unit twice-weekly requires 1.84 min per collection or a total of 3.68 min per week. Therefore twice-weekly collection is not justified on reasons of economy or efficiency, but should be used when health considerations warrant it.

Separate regression analyses based on collection frequency produced models with significantly different coefficients (Table 10). For once-weekly collection, X_1, the number of dwelling units per load, is the most highly correlated variable to productive time. The small coefficient for number of items collected produces only a minor increase in productive time required to collect an increased number of items per dwelling unit. For twice-weekly collection, X_2, the number of items collected per load, is the most highly correlated with productive time. Small changes in items per dwelling unit have a significant effect on the productive time, due to the large coefficient, 0.47, of this variable. Therefore, communities with more wastes per dwelling unit would theoretically increase efficiency significantly by using once-weekly collection.

Use of the regression models based on collection frequency is not necessary since the general model takes into account the effects of different collection frequencies. More frequent collection increases variables X_1 and X_5, decreases X_2, and vice-versa for less frequent collection. The general model explains

TABLE 10

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS BY COLLECTION FREQUENCY

Frequency of collection	Variable						R_2 Percent variation explained
	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway	X_4 Distance vehicle to storage	X_5 Route distance per load	X_0 Constant term	
Once per week	*0.72	0.09	0.005	0.066	3.36	0.38	78.5
Twice per week	0.48	*0.47	0.017	0.079	3.87	-3.32	77.8
All frequencies combined	*0.80	0.13	0.007	0.086	3.45	-0.78	81.5

*Variable most highly correlated with productive time a higher percentage of the variation in the total data than each of the models based on collection frequency (Table 10).

Collection Agency. Regression analyses were made on the data separating private and municipal satellite vehicle operators to determine any differences in efficiency (Table 11). The six agencies observed operated under the incentive system, thus eliminating efficiency differences due to this factor. Substituting average values for variables X_1 through X_5 (Table 3) and values for E_S and U from Table 12 into the private and public operator models shows the private operators to be 22 percent faster than the public operators.

Satellite Vehicle Type. Of the four types of satellite vehicles studied, three had the required capabilities to cope with all types of route conditions. The Trash Taxi was observed during its first week of operation and it did not have adequate power to climb hills and steep driveways at a reasonable speed, thus significantly slowing down the collection process.

The expertise and collection habits of the individual satellite vehicle operator far outweighed any slight advantage one particular vehicle might have.

The specifications for each of the four vehicles observed are very similar (Table 13). The larger hopper size and faster unloading mechanism of the Trashmobile would appear to give it an advantage over the three-wheeled vehicles, but this advantage is eliminated by its lower mobility and maneuverability. Sepa-

TABLE 11

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS FOR PRIVATE AND PUBLIC COLLECTION

Collection agency	Variable						R_2 Percent variation explained
	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway	X_4 Distance vehicle to storage	X_5 Route distance per load	X_0 Constant term	
Private	*0.69	0.13	0.005	0.058	2.59	0.01	74.8
Public	*0.83	0.24	0.010	0.082	4.14	-1.78	90.1
All	*0.80	0.13	0.007	0.086	3.45	-0.78	81.5

*Variable most highly correlated with productive time.

TABLE 12

COMPARISON OF PRIVATE AND PUBLIC AGENCIES

Agency	E_S	U (min)	Y_T* (min)
Private	0.944	1.5	10.0
Public	0.947	1.6	12.9
All	0.945	1.5	11.3

*Using average values for variables X_1 through X_5 (Table 3).

TABLE 13

SATELLITE WASTE COLLECTION VEHICLE SPECIFICATIONS

	Cushman	Trashmobile (Datsun)	Trash Taxi	Westcoaster
Hopper capacity (yd^3)	1.25	1.5	1.25	1.5
Loading height (in.)	50.75	48		50
Overall height (in.)	70	62		71.25
Number of wheels	3	4	3	3
Wheel size	5.00/5.70 x 8	6.00 x 14	7.00 x 13 rear 5.50/5.70 x 8-front	5.00/5.50 x 8
Wheel base (in.)	72	99.8	87	81
Engine size (hp)	18	67 hp at 5,200 rpm	38 hp at 2,500 rpm	17.6 at 3,900 rpm
Transmission	3-speed standard	4-speed standard	2-speed	3-speed standard
Vehicle weight (lbs)	1,282	2,600		1,220 (w/o cab)
Overall length (in.)	115	165		106
Overall width (in.)	45.5	62		53
Turning circle (ft)	15	20	14.5	15

rate regression analyses for each vehicle did not reveal any efficiency differences, with the exception of the Trash Taxi (Table 14).

Since all the models have coefficients of the same order of magnitude and the vehicle type does not affect collection, there is no advantage to the use of the separate models, with the exception of the Trash Taxi.

Collection Area Terrain. Separate regression analyses were performed on the data from hilly collection routes and flat collection routes (Table 15). The regression model coefficients for each are very similar, with the model for flat areas yielding slightly lower load times for standard conditions. The time required to complete one load in flat areas was approximately 15 percent less than the time that would be required to service the same houses in a hilly area. The longer time required by the satellite vehicles operating in hilly areas was partly due to the reduced speeds of the vehicles when negotiating steep driveways and roads.

Homes located in hilly areas of the study were usually high income types and tended to be farther from the street than houses on flat terrain. The average distance traveled up the driveways of homes in hilly areas was 100 ft, but was only 80 ft for homes located on flat terrain. The longer distances from the street to the storage point for homes in hilly areas also resulted in longer walking distances for the satellite vehicle operators. Operators walked an average distance of 20 ft from their vehicle

TABLE 14

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS BY VEHICLE TYPE

Vehicle type	Variable						R_2 Percent variation explained
	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway	X_4 Distance vehicle to storage	X_5 Route distance per load	X_0 Constant term	
Cushman (301 loads)	*0.76	0.16	0.006	0.091	4.14	-2.45	82.3
Trashmobile (308 loads)	*0.72	0.16	0.001	0.043	2.03	0.74	76.2
Westcoaster (337 loads)	0.63	0.20	0.007	0.107	*5.04	-1.22	84.5
Trash Taxi (104 loads)	*1.06	0.25	0.019	0.047	4.81	-2.69	87.7
Combined (1,050 loads)	*0.80	0.13	0.007	0.086	3.45	-0.78	81.5

*Most highly correlated variable to productive collection time.

TABLE 15

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS FOR HILLY AND FLAT TERRAIN

Terrain	Variable						
	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway	X_4 Distance vehicle to storage	X_5 Route distance per load	X_0 Constant term	R_2 Percent variation explained
Flat (506 loads)	*0.73	0.12	0.006	0.074	4.13	-0.95	85.9
Hilly (544 loads)	*0.82	0.16	0.005	0.071	2.76	-0.03	75.3
Combined (1,050 loads)	*0.80	0.13	0.007	0.086	3.45	-0.78	81.5

*Most highly correlated variable to productive collection time.

to the storage location in hilly areas and only 10 ft in flat areas.

Unless an area has exceedingly steep hills and driveways, similar to those observed in Pasadena, California, the regression model for all areas combined should be used. The variables X_3, X_4, and X_5 account for the longer distances to be expected in hilly areas. The special model for hilly areas should only be used when reduced satellite vehicle speeds are expected from excessive gradients on collection routes, streets, and driveways.

Type of Item Collected. The type of item which is collected by a satellite vehicle operator affects collection efficiency. Containers without handles and having excessive container weight require more time to transfer to the satellite vehicle from the storage point and unload.

The items collected in Knoxville, Tennessee were classified into three groups to determine the effect of the type of item collected on collection efficiency. The three groups were 55-gal drums, standard waste containers, and miscellaneous items. Of all the items classified in this manner, 68 percent were standard waste containers, 19 percent were miscellaneous items, and 13 percent were 55-gal drums.

A regression analysis was made with the items classified into three groups. The equation with the item classification included is:

$$Y_P = 0.59 + 0.71X_{.} + 0.22X_{2c} + 0.30\ X_{2b} + 0.14X_{2m} + 0.03\ X_4 + 2.04X_5$$

where Y_P = productive time required per load

X_1 = number of dwelling units serviced per load

X_{2c} = total number of standard containers collected

X_{2b} = total number of 55-gal drums collected

X_{2m} = total number of miscellaneous items collected

X_4 = average distance, in feet, from the satellite vehicle to the storage point at each dwelling unit

X_5 = route distance, in miles, which the satellite vehicle travels per load

This equation was able to explain 70.4 percent of the total variation in the data, and the standard deviation of the residuals was 19.8 percent of the response mean, productive time. The coefficient for 55-gal drums collected, 0.30, is more than twice as large as the coefficient for miscellaneous items collected, and 35 percent greater than the coefficient for standard containers collected. Thus, whenever a 55-gal drum is used instead of a standard container, the pickup time per item is increased by 35 percent.

Miscellaneous items were usually paper or plastic bags or cardboard boxes which were tossed into the satellite vehicle hopper, leaving no container to be returned to the storage point. The small coefficient for miscellaneous items, 0.14, illustrates the lower collection time required for such items as compared to standard containers which must be returned to their original storage position.

Fifty-five gallon drums are cumbersome, difficult to empty, potentially dangerous to the health of the collector and the homeowner, and should be restricted from usage as waste containers in all communities. If a satellite vehicle operator collects 15 55-gal drums per load instead of 15 standard waste containers, the productive time required to service 6 dwelling units would be increased 14 percent.

Additional study is being conducted by the Bureau on the effect of type of container on collection efficiency to determine the optimum container size and weight from the standpoint of the collector.

Weather Conditions. All of the field studies were conducted under ideal summer weather conditions. The satellite vehicle capabilities were not evaluated in the winter, but users reported no difficulties until there was more than 2 in. of snow on the ground. It would appear that ice or larger accumulations of snow could seriously impede the efficiency of satellite vehicles to the point where a conventional walking collector could be of equal or greater efficiency.

In areas of high temperature and humidity, the satellite vehicles offer relief from fatigue and heat exhaustion by reducing the amount of walking that a conventional walking collector normally does.

Packer Truck Driver Operational Analysis

Twelve packer truck drivers, working in conjunction with the satellite vehicle crews were observed and evaluated during the study. Five of these drivers collected wastes in addition to their primary driving duties. Of the five drivers that collected wastes, four acted as conventional walking collectors and one used a satellite vehicle.

Regression analyses were run on the four drivers serving as walking collectors individually and together, to describe the time required to service the dwelling units collected by the driver between truck moves (Table 16). The productive collection time, T, can be accounted for by the variables: b_1, the number of dwelling units serviced by the driver between truck moves; b_2, the total number of items collected from b_1 dwelling units; and b_3, the average distance from the truck to the dwelling unit waste storage location. The values for these variables for a particular community are determined in the same way in which the similar variables in the satellite vehicle collection model are determined.

The packer truck driver collection model resulting from the regression analysis of 592 data points for the four drivers was:

$$T = 0.60b_1 + 0.31b_2 + 0.011b_3 - 0.60$$

TABLE 16

PACKER TRUCK DRIVER COLLECTION MODEL COEFFICIENTS ALL STUDY SITES

Driver	Variable				R_2
	b_1 Number of dwelling units serviced between truck moves	b_2 Number of items collected	b_3 Average distance truck to storage	b_0 Constant term	Percent variation explained
$KG25_1$	0.63	*0.30	0.008	-0.29	59.9
$KG25_2$	0.56	*0.34	0.012	-0.98	83.8
$MH20_1$	*0.60	0.44	0.009	-0.71	87.1
$MH20_2$	*0.59	0.16	0.010	-0.37	84.9
Combined	0.60	*0.31	0.011	-0.60	75.9

*Most highly correlated variable to productive collection time.

This equation was able to explain 75.9 percent of the total variation in the data, and the standard deviation of the residuals was 31.8 percent of the response mean, productive collection time. The model coefficient values are similar to those for the individual drivers (Table 16), indicating the validity of the model, despite different operating conditions.

Regression Model Analysis. The regression model consists of three variables which accurately describe the productive collection time required to service b_1 dwelling units between truck moves. A discussion of each of the variables will illustrate their significance and how they may be estimated for design purposes.

b_1, Dwelling Units Serviced Between Truck Moves. The number of dwelling units serviced between truck moves by the truck driver was the second most important variable in describing the productive time required. The correlation coefficient between b_1 and Y_T was 0.691 for 592 observations.

The average number of dwelling units serviced between truck moves was two (Table 17). The values for b_1 ranged from one to five, but the drivers rarely collected more than 3 dwelling units between truck moves (Figure 22).

b_2, Total Number of Items Collected Between Truck Moves. The total number of items collected by the truck driver between moves was the most significant variable in describing the

TABLE 17

AVERAGE VALUES FOR PACKER TRUCK DRIVER COLLECTION VARIABLES

Driver	Number of data points	Variable			
		b_1 Number of dwelling units serviced between truck moves	b_2 Number of items collected	b_3 Average distance truck to storage (ft)	T Productive time (min)
$KG25_1$	218	1	3	90	2.0
$KG25_2$	138	2	4	80	2.4
$MH20_1$	120	2	3	80	2.3
$MH20_2$	116	2	2	50	1.6
Combined	592	2	3	80	2.1

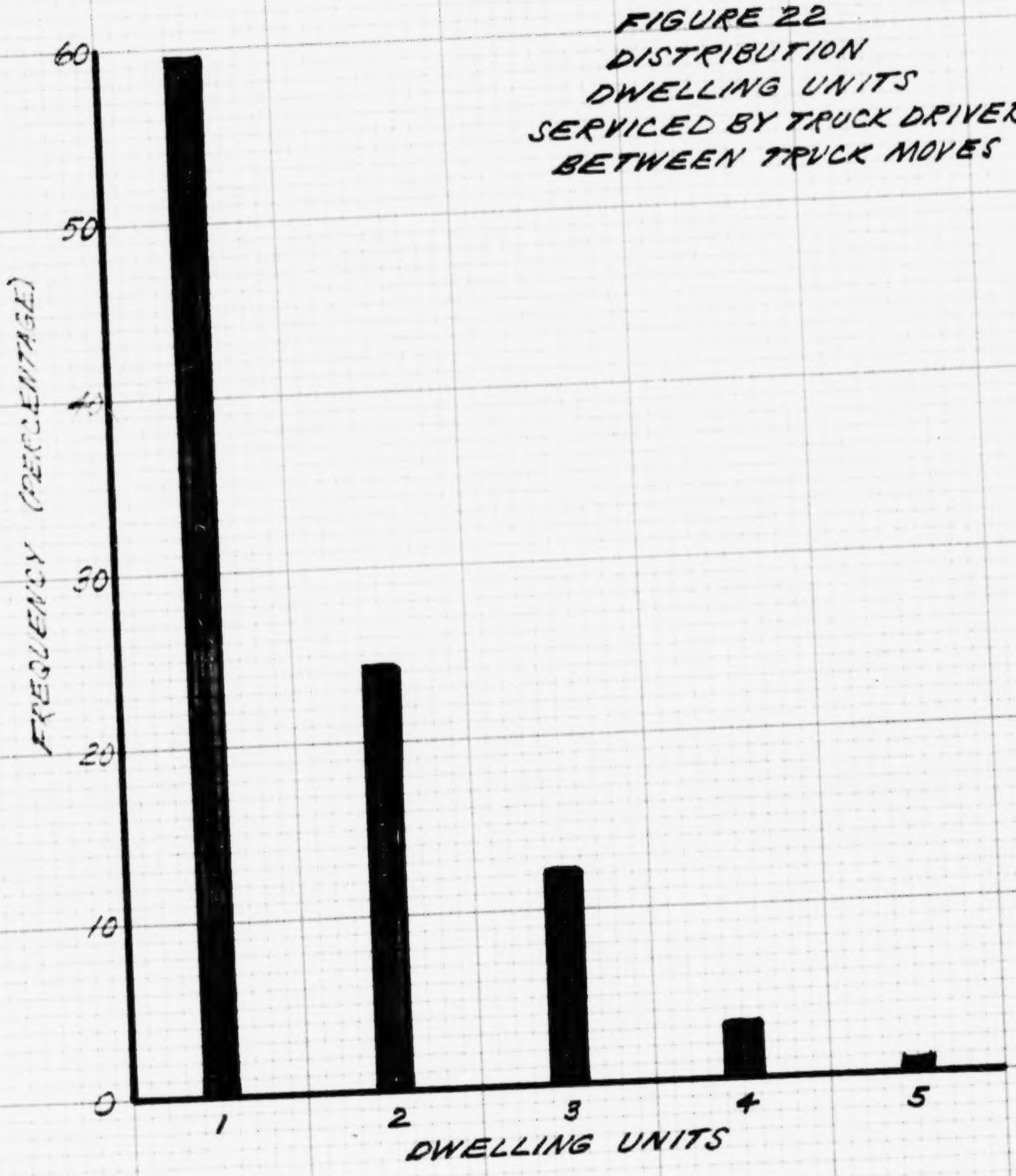

FIGURE 22
DISTRIBUTION
DWELLING UNITS
SERVICED BY TRUCK DRIVER
BETWEEN TRUCK MOVES

productive time required to service b_1 dwelling units. The correlation coefficient between b_2 and T was 0.755.

The average number of items collected between truck moves was three (Table 17). The values for b_2 ranged from 0 to 14 with a median value of 2 (Figure 23).

B_3, Average Distance From Packer Truck to Waste Storage Location. The average distance from the packer truck to the waste storage area for b_1 dwelling units serviced between truck moves was the least important of the three variables used. The correlation between b_3 and T was 0.365.

The average value for b_3 was 80 ft and the range was from 0 to 160 ft (Figure 24). The drivers usually serviced dwelling units with shorter street to storage distances than those serviced by the satellite vehicle operators in the crew.

Packer Truck Driver Activity Analysis. All of the 12 packer drivers observed during the field study devoted less than 20 percent of their time to driving the truck (Table 18). Therefore, 80 percent of the driver's time is available for collection or assistance to the satellite vehicle operators. To effectively assist a crew of two satellite vehicle operators should require approximately 20 percent of the driver's time. Of the remaining 60 percent, 45 percent should be devoted to collection, 10 percent to waiting at the truck and 5 percent to other time. Each additional crew member would require 10 percent of the driver's

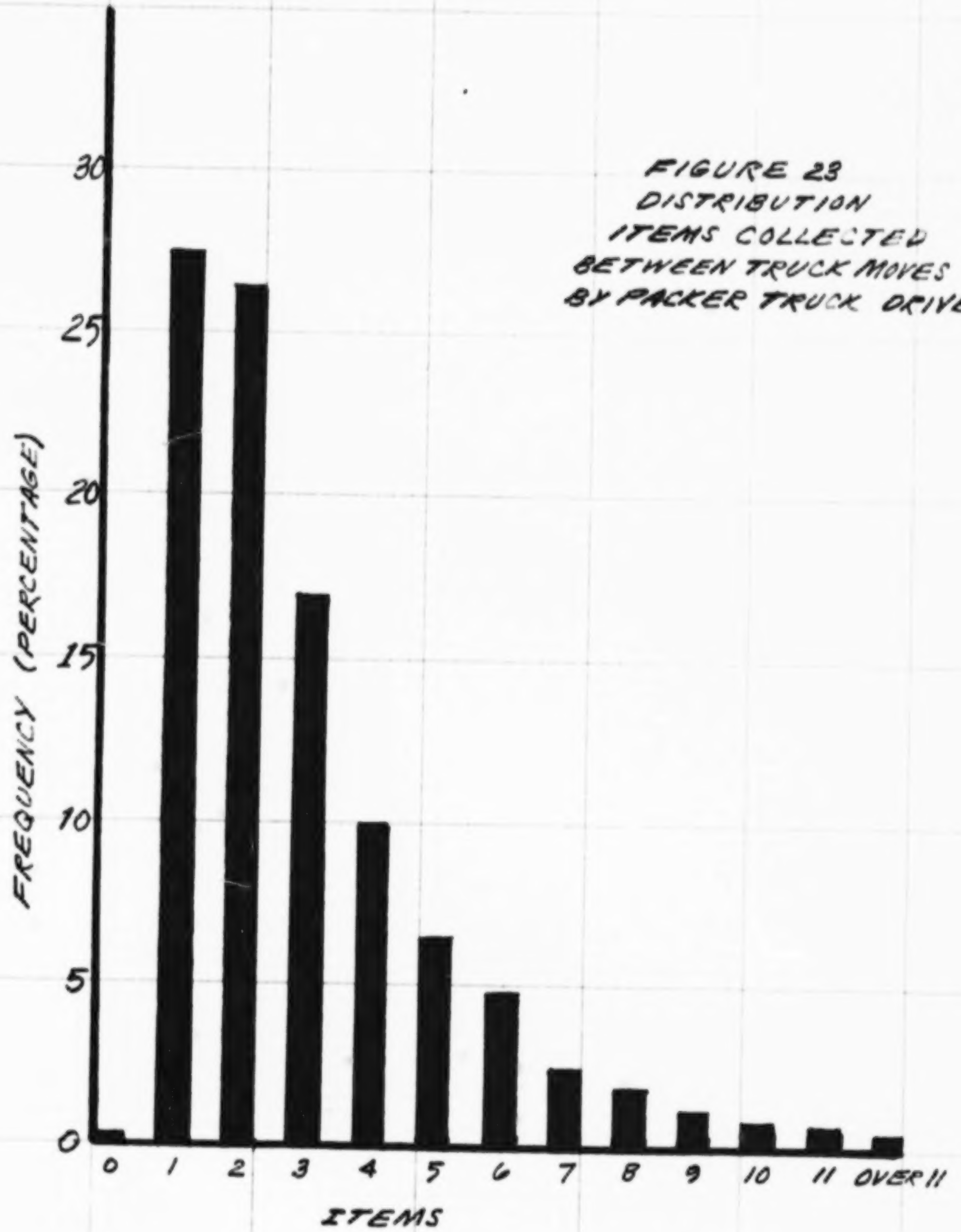
FIGURE 23
DISTRIBUTION
ITEMS COLLECTED
BETWEEN TRUCK MOVES
BY PACKER TRUCK DRIVER
FREQUENCY (PERCENTAGE)
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
11
OVER 11
ITEMS

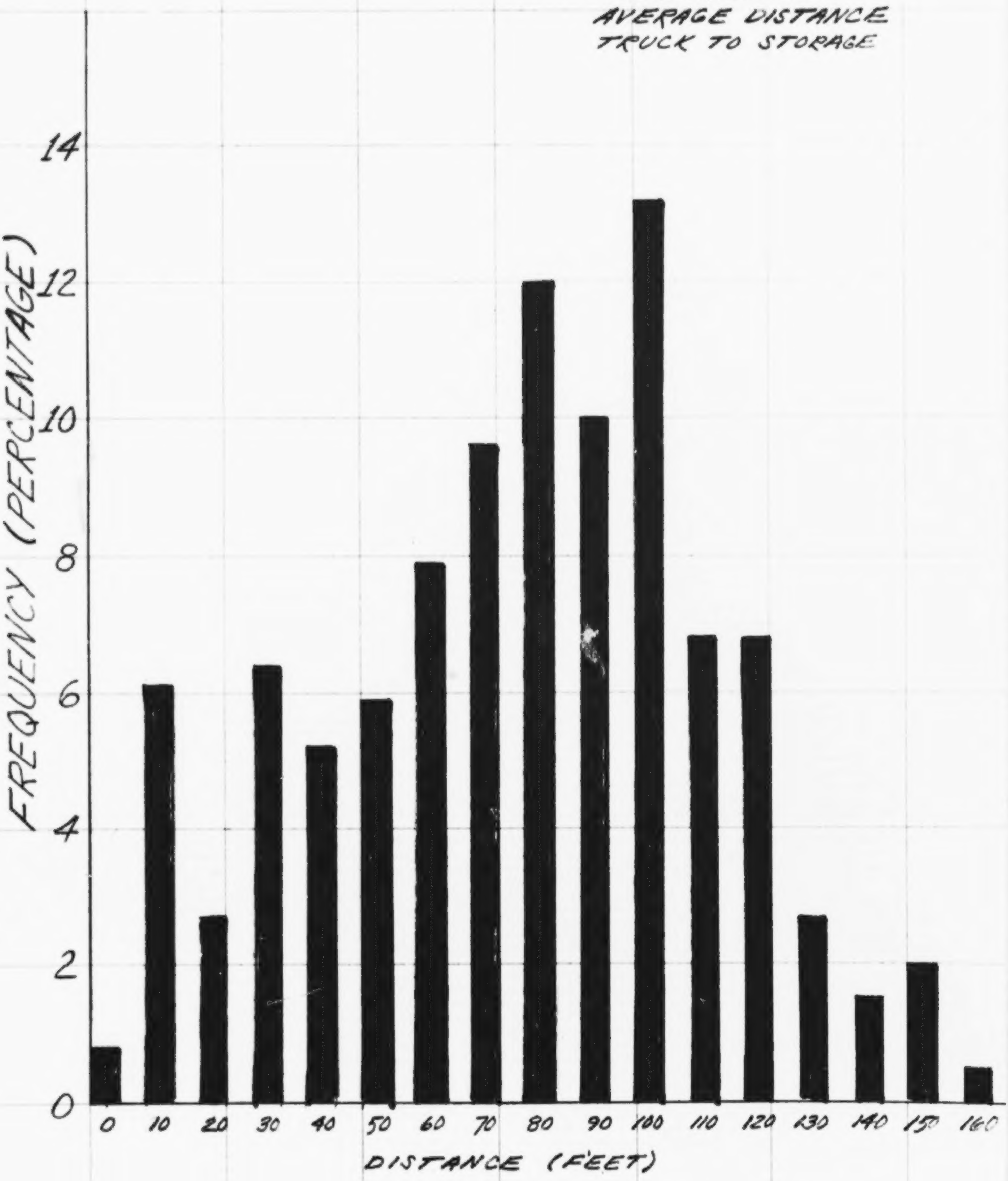
FIGURE 24
DISTRIBUTION
AVERAGE DISTANCE
TRUCK TO STORAGE
FREQUENCY (PERCENTAGE)
0
2
4
6
8
10
12
14
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DISTANCE (FEET)

TABLE 18

ANALYSIS OF PACKER TRUCK DRIVER ACTIVITY

Study site	Observed Crew size*	Percent of total time observed				
		Driving time	Collection time	Assistance time	Waiting time	Other time
Atlanta, Georgia	3	14.7	0.3	7.0	76.3	1.7
Columbia, South Carolina	5	19.4	1.5	6.5	61.8+	10.8
Knoxville, Tennessee	3	18.1	43.3	17.1	9.2	12.3
Medford, Oregon	3	18.4	45.8	13.3	3.2	19.3
Pasadena, California	5	19.9	2.4	49.7	22.3	5.7
Waukesha County, Wisconsin*	2	5.9	87.9	2.5	0.3	3.4
Average for private agencies		14.1	59.0	11.0	4.2	11.7
Average for public agencies		18.0	1.4	21.1	53.5	6.1
Average for all sites		16.1	30.2	16.0	28.8	8.9

*Crew activities explained in individual appendices.

+Drivers required to remain in trucks when on slope because of faulty emergency brakes.

time, correspondingly reducing the time available to the driver for collection.

All of the packer truck drivers in the private agency crews did some collection. These drivers collected an average of 59.0 percent of the available time, while the amount of time devoted to collection by the municipal packer truck drivers was negligible (Table 18).

SYSTEMS COST ANALYSIS

The cost information obtained from the six collection agencies studied was compiled and analyzed to determine the cost of residential waste collection using satellite waste collection vehicles. The daily crew costs, annual collection costs per dwelling unit and collection costs per ton were calculated for each of the study sites to evaluate the economics of satellite vehicle waste collection.

Daily Crew Costs

The costs associated with satellite vehicle waste collection systems are labor, satellite vehicle operation and depreciation, packer truck operation and depreciation, and overhead. The costs reported in the six study areas varied widely due to different economic levels, price and wage indices, and accounting methods used across the country (Table 19). The average daily crew cost was $130.82 per day, for a crew of two satellite vehicles with operators and a packer truck with a driver.

Labor. The wages and fringe benefits of crew personnel varied significantly from one section of the country to another (Table 19). Labor costs ranged from $79.97 to $195.62 per day. The wages and fringe benefits paid to the packer truck driver were usually slightly higher than those of the satellite vehicle operators. The packer truck driver was frequently designated as

TABLE 19

CREW* COSTS FOR SATELLITE VEHICLE COLLECTION

Study site	Dollars per day						
	Two satellite vehicles		Packer truck		(3 men)	Overhead+	Total
	Depreciation	Operation	Depreciation	Operation			
Atlanta, Georgia							
(Trash Taxi	5.20	9.22	9.28	5.46	67.78	19.39	116.33
(Trashmobile)	4.62	5.58	9.28	5.46	67.78	18.54	111.26
Columbia, South Carolina	5.00	3.20	7.21	5.78	45.45	13.33	79.97
Knoxville, Tennessee	9.20	5.98	17.69	10.00	60.95	20.76	124.58
Medford, Oregon	3.52	5.60	6.15	13.76	84.82	22.77	136.62
Pasadena, California							
(Hilly)	19.08**		30.90**		137.91	-++	187.89
(Flat)	19.08**		39.63**		137.91	-++	195.62
Waukesha County, Wisconsin	11.54	7.70	14.40	9.61	72.00	23.05	138.30
Average of all sites	7.28	6.57	12.02	10.33	78.15	16.24	130.82

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[*] A crew is defined here as two satellite vehicles with operators and a packer truck with a driver, except in Waukesha County, Wisconsin where the crew consisted of two operators, one of whom also acted as the packer truck driver.

[+] Overhead was estimated to be 20 percent of all other crew costs.

[**] Equipment costs reported by Pasadena are based on rental charges and are not broken down into operation and depreciation.

[++] Overhead is included in equipment and labor costs.

the crew foreman or chief, and was responsible for the crew's activities.

Labor costs accounted for an average of 60 percent of the total costs associated with a three-man satellite vehicle collection crew.

Satellite Vehicle Operation and Depreciation. The operational costs of satellite vehicles depend upon the operator treatment and maintenance program to which it is subjected. Operational costs averaged $3.29 per satellite vehicle per day for the areas investigated. Maintenance costs comprised the major portion of the operating costs as the satellite vehicle's lightweight construction and small engines are exposed to much abuse. The four-wheeled vehicles observed had lower maintenance costs than the three-wheeled vehicles due to their heavier duty construction. Fuel costs are very low since the satellite vehicles average approximately 80 miles per gallon and seldom travel more than 20 miles per day. Operating costs accounted for an average of 5 percent of the total costs of a three-man satellite vehicle crew.

The depreciation costs of the satellite vehicles depend upon their initial cost and assigned useful lives. Initial costs of three-wheeled satellite vehicles ranged from $2,100 to $3,000 depending upon the number of vehicles purchased and the optional equipment desired by the purchasing organization. The four-wheeled vehicles cost approximately $3,600. The useful lives of the vehicles ranged from 2 to 5 years depending upon the amount of abuse the vehicles were subjected to and the preventive maintenance programs of the owners. The average depreciation cost was $3.64 per satellite vehicle per day. The depreciation cost accounted for an average of 6 percent of the total cost of a three-man collection crew.

The average satellite vehicle operation and depreciation costs accounted for 11 percent of the total crew cost in the six systems studied.

Packer Truck Operation and Depreciation Costs. Packer truck operating costs depend primarily upon the size of the truck chassis and the abuse which it is given. The average operating cost for the packer trucks operated in the study areas was $10.33 per day.

Packer truck operating costs accounted for an average of 8 percent of the total costs of a three-man satellite vehicle collection crew.

The depreciation costs of a packer truck depend on the initial cost and the estimated useful life. The cost varies primarily as a function of the capacity of the packer unit. The most commonly encountered packer trucks had 18 and 20 cu yd capacities and an approximate initial cost of $15,000. Useful lives assigned to packer trucks ranged from 4 to 10 years in the six areas studied. Packer truck depreciation averaged $12.02 per day and accounted for 9 percent of the total crew cost.

The average packer truck operation and depreciation costs accounted for 17 percent of the total satellite vehicle waste collection crew costs.

Overhead. Overhead costs were not available from five of the six collection agencies studied and therefore it was estimated to be 20 percent of all other crew costs. This figure is based upon known overhead costs from communities with adequate accounting records. Based on this assumption, overhead cost averaged 12 percent of the total satellite vehicle waste collection crew costs.

Annual Collection Cost per Dwelling Unit

The homeowner judges the effectiveness of any residential waste collection system by the cost which he must bear for the particular level of service he receives. As the level of service increases, the cost must increase correspondingly. Backyard collection costs more than curbside; twice-weekly collection more than once weekly. Within a backyard collection system a house 200 ft from the road requires more time and therefore more money to service than a similar house 100 ft from the road.

If one house has three items to be collected and another has only two, the former will cost more to service even if all other things are equal. Therefore, in order to make valid comparisons between any two collection systems all of the variables must be accounted for.

The actual annual collection cost per dwelling unit for the average conditions observed in each study site ranged from $11.00 to $46.00 per year, not taking into account any other influences (Table 20). These costs cannot be compared as they occurred under distinctively different sets of conditions. There is no such thing as an average cost of collection. There is such a thing as an average cost of collection for a particular dwelling unit and a crew operating under given costs. To change any characteristics of the dwelling unit or one of the costs contributing to the total daily crew costs changes the cost of service to that dwelling unit.

To compare the cost of service provided by any two satellite vehicle collection crews requires that they service dwelling units with identical characteristics and have identical labor, equipment and overhead costs. Evaluating a number of crews under the same basic operating conditions will then produce an average cost to service a dwelling unit taking into account all influencing factors.

Using the average values for the variables recorded during the study, the average daily crew cost and the satellite vehicle and packer driver collection regression models for each study site, the annual collection cost per average dwelling unit for once-weekly and twice-weekly collection was calculated. The average values used in the calculations were:

X_1 = five dwelling units for once-weekly collection

TABLE 20

ESTIMATED COST OF RESIDENTIAL SOLID WASTE COLLECTION USING SATELLITE VEHICLES, UNDER ACTUAL COMMUNITY CONDITIONS

Study site	Collection frequency per week	Cost (dollars)			
		Per dwelling unit			Per ton*
		Per collection	Per week	Per year	
Atlanta, Georgia					
(Trash Taxi)	2	0.32	0.62	33.50	24.00
(Trashmobile)	2	0.22	0.44	21.50	15.50
Columbia, South Carolina	2	0.33	0.66	31.50	15.50
Knoxville, Tennessee	1	0.20	0.20	11.00	5.50
Medford, Oregon	2	0.25	0.50	25.50	15.50
Pasadena, Califronia					
(Hilly)	1	0.88	0.88	46.00	22.00
(Flat)	1	0.57	0.57	28.50	19.50
Waukesha County, Wisconsin	1	0.33	0.33	17.00	8.50

*The amount of solid waste collected was weighed in Atlanta, Medford, Pasadena, and Waukesha County. An estimate of 3.0 lb per capita per day was used for Columbia and Knoxville, where weighings were not made.

X_1 = 10 dwelling units for twice-weekly collection

X_2 = 15 items per load for once or twice-weekly collection

X_3 = 90 ft

X_4 = 10 ft

X_5 = 0.45 miles for once-weekly collection

X_5 = 0.75 miles for twice-weekly collection

U = 1.0 min

E_s = 95 percent

H = 6.0 hr

Z = three men

C_L = $26.05 per day

C_T = $22.35 per day

C_s = $6.93 per day

C_o = $16.24 per day

b_1 = two dwelling units

b_2 = six items for once-weekly collection

b_2 = three items for once-weekly collection

b_3 = 100 ft

E_D = 45 percent

Collection Frequency Effects on Cost. For once-weekly collection the average annual cost per average dwelling unit for standard conditions was $19.00 per year and for twice-weekly collection the average cost was $28.50 per year (Table 21). Therefore, using standard conditions, once-weekly collection costs approximately 33 percent less than twice-weekly collection.

TABLE 21

COST ESTIMATES FOR SATELLITE VEHICLE WASTE COLLECTION SERVICE, IDENTICAL CONDITIONS BEING ASSUMED

Study site	Once-a-week collection		Twice-a-week collection	
	Per dwelling unit per year	Per ton	Per dwelling unit per year	Per ton
Atlanta, Georgia				
(Trash Taxi)	23.50	12.50	38.50	20.00
(Trashmobile)	22.50	11.50	30.00	15.50
Columbia, South Carolina	27.00	14.00	41.00	21.50
Knoxville, Tennessee	14.50	7.50	22.50	11.50
Medford, Oregon	16.00	8.00	22.50	11.50
Pasadena, California	19.50	10.00	28.50	15.00
Waukesha County, Wisconsin	15.00	8.00	23.00	12.00
Average of all sites	19.00	10.00	28.50	15.00
Average for private agencies	15.00	8.00	22.50	11.50
Average for public agencies	23.00	12.00	34.50	17.50

Collection Agency Effects on Cost. Cost to private collection agencies averaged $15.00 per dwelling per year for once-weekly collection, while public agencies averaged $23.00 per dwelling unit per year, when all other influences were taken into account. Twice-weekly collection by private agencies averaged $22.50 per dwelling unit per year, while identical service by public agencies averaged $34.50 per year. The 53 percent lower collection costs achieved by private agencies was due solely to higher crew efficiencies (dwelling units serviced per hour). The higher crew efficiencies were due to the fact that the private packer truck drivers also collected, thus contributing to the total number of dwelling units serviced per hour by the private agency vehicle operators were slightly faster than public operators (Tables 12, 18). This does not refer to the costs charged to residents for service but is related only to the time needed for collection by each type of agency.

Collection Cost per Ton

Collection costs per ton were calculated for the average dwelling units observed at each study site (Table 20). Also, collection costs per ton were determined for each study site using the average variable values used in the annual collection cost per dwelling unit calculations (Table 21). For these calculations, the standard dwelling unit was assumed to have an average of 3.5 occupants with a waste generation rate of 3.0 lb per person per day.

The same lower costs for once-weekly collection and collection by private agency result from these calculations (Table 21). The actual costs per ton achieved by the crews in the six study areas ranged from $5.50 to $24.00 per ton, disregarding all influencing factors (Table 20). A recent national survey of national collection practices, disregarding type of frequency of collection, gives an average cost of $13.08 per ton for 10 cities providing backyard collection.[3]

Development of Cost Estimation Model

Ideally, the designer of residential waste collection systems would like to be able to estimate the collection cost per dwelling unit serviced by any type of collection system in order to make economic comparisons between alternative systems without actual trial implementation. Such a cost estimation model can be developed from the satellite vehicle operator and packer truck driver collection regression models that would take into account all of the factors peculiar to each community that affect cost of collection.

The large number of factors which affect the collection cost of a dwelling unit by any method make cost comparisons from one community to another meaningless, unless all influencing factors are accounted for. Each community is a unique case and must account for its own particular housing characteristics and labor situation to determine the most economic collection system. A cost estimate per dwelling unit can be obtained by multiplying the true crew cost per hour by the reciprocal of the estimated crew efficiency.

The following are derivations of true crew cost per hour and crew efficiency.

True Crew Cost per Hour. The costs associated with [illegible] satellite vehicle collection crew are:

C_L, the wages and fringe benefits per man per day

C_T, packer truck operation and depreciation per day

C_S, satellite vehicle operation and depreciation per day

C_O, overhead cost of the system per day

It must be emphasized that only those hours devoted to the actual collection process are used in the calculation of true hourly crew costs in order to prorate the cost of the non-collection activities, such as break times and going to or grom the garage or disposal site, among the dwelling units which are serviced during the actual collection process. This method allows the total costs to be included in those hours which the collectors are collecting. The total true cost per hour of any satellite vehicle collection crew may be expressed as

$$C_c = \frac{ZC_L + C_T + (Z-1)C_S + C_o}{H}$$

where C_c = true crew cost per hour

Z = number of men in crew

H = number of hours devoted to the actual collection process

Crew Efficiency. Crew efficiency is the total number of dwelling units which a residential waste collection crew collects per unit time. For this report on satellite vehicle collection the crew efficiency is defined as the total dwelling units collected per hour by each satellite vehicle operator and the packer truck driver.

The total time required by a satellite vehicle operator to service X_1 dwelling units in one load is expressed by the equation:

$$Y_T = \frac{0.80X_1 + 0.13X_2 + 0.007X_3 + 0.086X_4 + 3.45X_5 - 6.78 + U}{E_s}$$

where Y_T = total time required to service X_1 dwelling units in one load, in minutes

X_1 = dwelling units per satellite vehicle load

X_2 = total items collected from X_1 dwelling units

X_3 = average distance satellite vehicle travels up dwelling unit driveways, in feet

X_4 = average distance from satellite vehicle to waste storage point, in feet

X_5 = route distance of satellite vehicle per load, in miles

U = satellite vehicle unloading time, in minutes

E_s = fraction productive and unloading time of total time on collection route of satellite vehicle operator

Dividing Y_T by X_1 yields minutes per dwelling unit. Multiplying Y_T by 1 hr per 60 min yields hours per dwelling unit. Inverting Y_T produces the number of dwelling units serviced per hour by a satellite vehicle operator. The resulting equation is:

Dwelling units per hour =

$$\frac{60X_1}{Y_T}$$

A crew of Z men has (Z-1) satellite vehicle operators, unless the packer driver also operates a satellite vehicle as in Waukesha County, Wisconsin. The total number of dwelling units serviced per hour by the satellite vehicle operators is then:

$$\frac{60X_1\ (Z-1)}{Y_T}$$

The total time which a packer driver requires to service b_1 dwelling units between truck moves is expressed by the equation:

$$T = 0.60b_1 + 0.31b_2 + 0.011b_3 - 0.60$$

where T = total time in minutes to service b_1 dwelling units between truck moves

b_1 = number of dwelling units serviced between truck moves

b_2 = total number of items collected from b_1 dwelling units

b_3 = average distance from packer truck to waste storage location, in feet

Dividing T by b_1 yields the number of minutes per dwelling unit. Since the packer driver only devotes a certain fraction of each hour, E_D, to collection, the minutes per dwelling unit must be divided by E_D. Converting minutes to hours and inverting the model produces the total number of dwelling units serviced per hour by the packer truck driver is:

$$\frac{60b_1E_D}{T}$$

The crew efficiency in total number of dwelling units per hour for collection crew using satellite vehicles is:

$$\frac{60X_1\ (Z-1)}{Y_T} + \frac{60b_1E_D}{T}$$

Cost Estimation Model. The annual collection cost per dwelling unit, for N collections per year, is obtained by multiplying the expected true crew cost per hour by the reciprocal of crew efficiency, hours per dwelling unit. The cost estimation model is:

$$C = \frac{ZC_L + C_T + (Z-1)C_S + C_o}{H} \left[\frac{1}{\frac{60X_1\,(Z-1)}{Y_T} + \frac{60b_1E_D}{T}} \right] \qquad (N)$$

To compute an estimate of the annual collection cost per dwelling unit for a satellite vehicle crew, the designer first determines his particular costs, estimates operational characteristics from the previous analysis of variables based on physical route and housing characteristics, and then places them into the cost estimation model for calculation. The cost estimate obtained is then compared to the cost estimates for other methods of conventional collection produced from similar collection regression models for backyard collection service (Appendix A).

Quantitative and qualitative comparison of different waste collection methods permits a rational and responsible decision for the type of waste collection system to be used in any community.

SATELLITE VEHICLE WASTE COLLECTION VS. CONVENTIONAL COLLECTION

A residential solid waste collection system should attempt to provide the most conventional, aesthetic and sanitary service possible to the customer in the most efficient and economical manner in conformance with the health, safety and morale of the collection agency personnel. Comparison of one collection system with another requires qualitative and quantitative evaluation of each of these desirable features.

Qualitative Evaluation

The following statements are the author's opinions, based on observations and user reports, since they are not subject to numerical analysis.

The most convenient waste collection service which can be provided to a homeowner is collection of wastes from the point of storage. This service may be provided by collectors walking or riding satellite waste collection vehicles. From observation of both methods, collectors using satellite vehicles provide a more sanitary service since walking collectors tend to spill wastes around the storage area in their attempt to minimize their number of trips to the packer truck by transferring and consolidating wastes from several containers into their own carry container. The satellite vehicle operator has a 1- to 2-cu yd carrying capacity at his disposal and is content to merely dump the wastes from the homeowner's container into the satellite vehicle hopper. In addition, the homeowner views the satellite vehicle as a technological advance on the part of the collection agent, thus eliminating a portion of his natural psychological adversity to the waste collector.

Use of satellite vehicles facilitates the work of the collection personnel. For the average dwelling unit located 100 ft from the street, the satellite vehicle operator would walk a total of 20 ft, but a walking collector would be required to walk 300 ft (Appendix A). Thus the physical work required of the collector is reduced 93 percent. As a result, the men do not tire physically and are not as frequently exposed to injuries from lifting and carrying excess weight. The six agencies studied reported significant increases in satellite vehicle operator morale and corresponding decreases in employee absenteeism. Increased morale is partially attributable to the fact that satellite vehicle operators assume an aura of status over their walking peers, as laborers operating machinery are usually more highly regarded and more highly compensated than manual laborers. In addition, satellite vehicles provide shelter for the collector during inclement weather.

Satellite vehicle usage indirectly affects packer truck operating and maintenance costs. Packer truck movements and mileage are reduced since the trucks remain on main streets while the satellite vehicles service narrower side streets. Thus operating and maintenance costs are reduced. In addition driveway and curb damage is reduced. Also the hazards to children playing in the collection area are significantly lowered, with reduced reverse movements of the packer truck.

Disadvantages of satellite vehicle usage are potential littering of collection areas, excessive noise and damage to dwelling unit property. The open hoppers of the satellite vehicles allow waste to be blown from them by high winds or high speed of the vehicle. Many vehicles made excessive noise which could bother some customers. Careless operators were observed to run the vehicles over lawns and flowers, causing some damage.

Quantitative Evaluation

The economy and efficiency of satellite vehicle collection systems can be evaluated quantitatively. A comparison of this method with the conventional backyard collection system using walking collectors reveals the relative economies and efficiency of one to the other.

Collection Efficiency. The efficiency of two collection systems can be determined by comparison of the total number of dwelling units each collection method could service under the same conditions. The satellite vehicle crew efficiencies observed in the six study areas were compared to the estimated efficiencies of conventional crews servicing the same areas (Table 22). It can be seen that in five of the six study sites the satellite vehicle crews were able to service more dwelling units per hour than the corresponding conventional crews. The calculations for the crew efficiencies are contained in the Appendices for each study site. Satellite vehicle crew efficiency ranged from 43 percent more efficient in Pasadena, California to 28 percent less efficient in Columbia, South Carolina.

Collection Economy. The ultimate comparison between alternative methods of residential waste collection is between their relative costs to accomplish the same objective. The annual collection cost per average dwelling unit observed for each study site was calculated for satellite vehicle collection and compared

TABLE 22

RESIDENTIAL WASTE COLLECTION COSTS AND CREW EFFICIENCIES SATELLITE VEHICLE METHOD VS. CONVENTIONAL METHOD

Study site	Collection frequency (per week)	Crew efficiency† (Dwelling units per hour)		Annual cost per dwelling unit*	
		Satellite vehicle	Conventional (estimated)	Satellite vehicle	Conventional (estimated)
Atlanta, Georgia					
(Trash Taxi)	2	56	47	33.50	33.50
(Trashmobile)	2	83	65	21.50	24.00
Columbia, South Carolina	2	48	67	31.50	18.50
Knoxville, Tennessee	1	77	62	11.00	12.00
Medford, Oregon	2	113	85	25.50	30.50
Pasadena, California					
(Flat)	1	71	45	28.50	37.50
(Hills)	1	38	36	46.00	44.50
Waukesha County, Wisconsin	1	61	50	17.00	17.00
All sites with once-weekly collection		64	51	21.50	23.50
All sites with twice-weekly collection		77	64	28.00	26.00

† For average observed conditions at each study site.

* For the average conditions observed and average crew cost reported at the six study sites.

with the estimated cost by conventional walking collectors (Table 22). Satellite vehicle collection costs were less than conventional collection costs in four cases, even in two cases, and more in two cases. Satellite vehicle collection costs ranged from 24 percent less to 70 percent more than the estimated cost per dwelling unit by conventional walking collectors. Therefore neither method of collection can be said to be more economical in all cases. In order to determine the most economical collection system for a particular community several factors must be considered and used in the cost estimation model previously outlined.

SATELLITE VEHICLE WASTE COLLECTION MODEL APPLICATION

The practical significance of the satellite vehicle waste collection model is based upon its capacity to accurately estimate the collection time necessary to service any given number of dwelling units in any given community. The following application is presented to demonstrate the validity of the model and the utility of the accompanying analyses in designing a satellite vehicle waste collection system.

The Village of Glendale, Ohio has a satellite vehicle waste collection crew for their residential waste collection, but was not one of the study sites used in the development of this report. The crew, consisting of a packer truck driver and two satellite vehicle operators, spends 330 min per day or 1,650 min per week on collection. The crew services approximately 854 dwelling units an average of 2½ times per week, for a total of 2,135 dwelling units per week.

By evaluating the factors analyzed in this report, and using them in the waste collection models, the collection time required can be estimated and compared to the actual time required given above. The satellite vehicle waste collection model is:

$$Y_T = \frac{0.80X_1 + 0.13X_2 + 0.007X_3 + 0.086X_4 + 3.45X_5 - 0.78 + U}{E_s} \qquad (1)$$

where Y_T = the total time, in minutes, to complete one satellite vehicle round trip

X_1 = the total number of dwelling units serviced in one round trip. As discussed earlier, X_1 is primarily a function of collection frequency, which in turn determines the number of items per dwelling unit Since garden wastes are combined with household wastes in Glendale it is estimated that the average dwelling unit has 3.9 items to be collected per week or approximately 1.5 per collection (Table 8).

$$X_1 = \frac{15}{\text{average number of items per dwelling unit}} =$$

$$= \frac{15}{1.5} = 10 \text{ (p 38)}$$

X_2 = the total number of items collected from X_1 dwelling units. The analysis of X_2 showed that the satellite vehicle averaged 15 items per load (p41).

X_3 = the average distance, in feet, which the satellite vehicle is able to drive up each dwelling unit driveway. This is a function of street to storage distance and accessibility. From the average Village house lot size it can be determined that the average street to storage distance is 90 ft.

$$D_{SS} = 0.83X_3 + 0.76X_4 + 11.4 \quad \text{(p 41)} \qquad (2)$$

$$90 = 0.83X_3 + 0.76X_4 + 11.4$$

The accessibility factor may be determined by a visual survey of the Village on collection day or by assuming the average value, 0.88, for A (Table 6).

$$A = \frac{X_3}{X_3 + X_4} \quad \text{(p 42)} \qquad (3)$$

$$0.88 = \frac{X_3}{X_3 + X_4}$$

Simultaneous solution of equations (2) and (3) determines the values of X_3 and X_4.

$$X_3 = 94 \text{ ft}$$

$$X_4 = 13 \text{ ft}$$

X_4 = the average distance, in feet, from the satellite vehicle to the waste storage location. This was calculated above and the value is 13 ft.

X_5 = the total route distance, in miles, of the satellite vehicle round trip. Route distance is a function of the housing density and the total number of houses serviced per load (p 47). Glendale has a housing density of 53 dwelling units per mile of street. The route distance per dwelling unit served is 0.114 miles (Figure 15). For 12 dwelling units the total route distance would then be approximately 1.35 per load.

U = the unloading time, in minutes, of the satellite vehicle at the packer truck. Assuming average operating practices by the crew in Glendale, using Cushman satellite vehicles, U is estimated to be 1.5 min (Table 9).

E_s = the fraction of the operator's total time which is occupied by collection and unloading activities. Since the operators are assumed to use good operating practices, the average value of E_s, 0.95, is used (p 61).

The determination of values for the variables in the satellite vehicle waste collection model was based on knowledge of three factors; the collection frequency, the housing density, and the average dwelling unit lot size. Thus, it can be seen that the design of the collection system does not require a field study and can be easily determined from common community records.

Substituting the values assigned into the model,

$$Y_T = \frac{0.80(10) + 0.13(15) + 0.007(94) + 0.086(13) + 3.45(1.35) - 0.78 + 1.50}{0.95}$$

$$= 18.0 \text{ min/satellite vehicle load}$$

The efficiency of the satellite vehicle operator is 10 dwelling units per 18.0 min or 33 dwelling units per hr.

The number of dwelling units per hour which the packer truck driver can service can be calculated using the packer truck driver collection model. These dwelling units have the same characteristics as those serviced by the satellite vehicle operators.

$$T = 0.60b_1 + 0.31b_2 + 0.011b_3 - 0.60 \quad (p\ 74)$$

where T = total time, in minutes, to service b_1 dwelling units between truck moves

b_1 = total number of dwelling units serviced by the packer truck driver between truck moves. The average value for b_1 observed during the study, 2, will be used here (Table 17).

b_2 = total number of items collected by the packer truck driver from b_1 dwelling units. The dwelling units in Glendale were estimated to have 1.50 items each. Therefore $b_2 = 3.00$.

b_3 = average distance, in feet, from the packer truck to the storage at each dwelling unit. If the average street to storage distance is 90 ft, the value for b_3 would be approximately 110 ft.

Substituting these values into the packer truck driver collection model;

$$T = 0.60(2) + 0.31(3.0) + 0.011(110) - 0.60 = 2.7 \text{ min}$$

A packer truck driver working efficiently can devote 30 percent of his time to collection (Table 18). Assuming this to be the case in Glendale, the efficiency of the packer truck driver is:

2 dwelling units/2.7 min x 60 min/hr x 0.30 = 13 dwelling units/hr

The crew efficiency can now be calculated:

crew efficiency = satellite vehicle operator efficiency
+ packer truck driver efficiency
= 2 (33 d.u./hr) + 13 d.u./hr
= 79 dwelling units per hr

Since the total number of dwelling units which must be serviced per week is known, then the total time required may be determined.

2,135 dwelling units/week x 1 hr/79 dwelling units
= 27.02 hr/week
$\simeq$ 1,620 min per week

The actual collection time required is 1,650 min per week or approximately 2 percent above the estimated collection time. Therefore, this application clearly illustrates the usefulness and accuracy of the satellite vehicle operator and packer truck driver collection models for designing satellite vehicle waste collection systems.

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ACKNOWLEDGMENTS

This study required the cooperation of many people and organizations. The Division of Technical Operations extends sincere appreciation to the personnel of the Division of Sanitation, City of Atlanta, Georgia; Department of Sanitation, City of Columbia, South Carolina; Sanitary Disposal Company, Knoxville, Tennessee; City Sanitation Service, Medford, Oregon; Sanitation Division, City of Pasadena, California; and Sanitary Disposal Service, Inc., Waukesha County, Wisconsin.

Members of the Division of Technical Operations participating in the field work were: Gregory Cole, Stephan Freedman, Jeffrey L. Hahn, Harry R. Little, Claude A. J. Schleyer, and Kenneth A. Shuster. Special thanks go to Betty L. Grupenhoff for her statistical services, which were a major contribution to the success of the study.

APPENDIX A

WALKING COLLECTOR REGRESSION MODEL

A regression model to describe productive collection time for residential waste collection by walking collectors has been developed by the Bureau in a manner similar to that for the satellite vehicle regression model. Data on 16 walking collectors were gathered in five U.S. cities, by following the collectors on their collection routes. Comprehensive analysis of the data is currently in progress and only the preliminary results have been used in this report.

The regression model which best describes the productive collection time required to service W_1 dwelling units is:

$$C = 0.18 - 0.12W_1 + 0.12W_2 + 0.24W_3 + 0.005W_4$$

where C = productive collection time required, in minutes, to service W_1 dwelling units

W_1 = number of dwelling units to be serviced

W_2 = total number of items to be collected from W_1 dwelling units

W_3 = total number of round trips which the collectors make to the packer truck. Preliminary analysis of the data indicates that an average of three items may be collected by the typical walking collector before he must return to the packer truck and empty his carry barrel. This relationship was assumed for the calculation of time estimates for the six areas where satellite vehicles were studied.

W_4 = the total distance, in feet, walked by the collector while servicing W_1 dwelling units. Preliminary analysis of the data indicates that the walking distance is a function of the street to storage distance for each dwelling unit. A regression analysis of street to storage distance against walking distance produced the equation:

$$W_4 = \left[45 + 2.55 \text{ (average street to storage distance)}\right] W_1$$

This equation was used in the time estimations for comparison of collection methods in the six satellite vehicle study sites.

The walking collector regression model was able to explain 92.6 percent of the total variation in the data, and the standard deviation of the residuals was 19.0 percent of the response mean, productive collection time.

The regression model for productive time does not include the non-productive or "other" time which normally occurs during the work day. Productive time accounts for approximately 85 percent of the average walking collector's time. When the walking collector also drives the packer truck his productive time is reduced to approximately 80 percent of his total time on the route.

APPENDIX B

FIELD STUDY, AUGUST 18-22, 1969, ATLANTA, GEORGIA

The Sanitary Division of the City of Atlanta Public Works Department is responsible for the collection and disposal of all residential wastes generated by the 502,500 inhabitants of Atlanta (Table B-1). The Division provides backyard collection of refuse twice weekly and curbside collection of garden wastes once weekly. The refuse collection department operates 127 packers and employs 1,025 men on 152 routes in 15 districts.

A shortage of manpower was the initial reason for Atlanta's purchase of 41 Cushman scooters in 1966. The Division suffered from an absentee rate which ran as high as 40 percent of the total department. The City found that two collectors with Cushman scooters could replace three walking men collecting with tubs. The Cushman scooters operated well and efficiently at first, but developed mechanical troubles 3 to 6 months after introduction into the system. Rugged usage over the hilly terrain in northern Atlanta caused the small 8 in tires to fail after 30 days. All of the Cushman vehicles became obsolete within 3 years.

The City then purchased a number of four-wheeled Trashmobiles to use in this area. The Trashmobiles worked well and are still in use, but they lack the maneuverability of the three-wheeled

TABLE B-1

CITY OF ATLANTA, GEORGIA
(from Atlanta Chamber of Commerce)

Population	502,500
Dwelling units	157,900
Persons per dwelling unit	3.18
Land area	136 sq miles
Population density	3,700 persons per sq mile
Dwelling unit density	1,160 dwelling units per sq mile
Miles of roads	2,057 miles
Dwelling units per street mile	80 dwelling units per mile

satellite collection vehicle as they must back out of driveways, thus causing a safety hazard. Recognizing the need for a heavy-duty vehicle, the City had the Trash Taxi designed to meet the requirements imposed by the varied terrain in northern Atlanta. The $1\frac{1}{4}$ cu yd hoppers from the obsolete Cushman scooters were used on the Trash Taxis. The Trash Taxi features a 13 in. wheel, a heavier brake, larger engine and hydraulic transmission to combat the problems previously encountered. Eighteen Trash Taxis were put into operation in August 1969 to supplement the 26 Trashmobiles currently in operation.

Field Study Analysis

The field study on Trash Taxi and Trashmobile operations in Atlanta was conducted August 18-22, 1969. Two crews using Trash Taxis were observed during the first 4 days of the study. Data were recorded on four Trash Taxi operators and two packer truck drivers. The final day was spent with a crew consisting of two Trashmobiles and a packer. Both Trashmobile operators and the packer driver were observed for 1 day.

Due to the distinct characteristics of these two types of satellite vehicles, their operations were analyzed and will be discussed individually.

Trash Taxi Collection Operational Analysis. One hundred and four data points were collected on Trash Taxi operations in Atlanta. Stepwise regression techniques were applied to two individual operators and also on all the operators together. The best regression model for describing productive collection time for the four Trash Taxi operators in Atlanta is: (Table B-2).

$$Y_P = -2.69 + 1.06X_1 + 0.25X_2 + 0.019X_3 + 0.047X_4 + 4.81X_5$$

where Y_P = productive collection time per satellite vehicle load, in minutes

X_1 = number of dwelling units serviced per load

X_2 = number of items collected per load

X_3 = average distance that the satellite vehicle goes up each dwelling unit driveway, in feet

X_4 = distance from satellite vehicle to storage point, in feet

X_5 = route distance of satellite collection vehicle per load, in miles

This model was able to explain 87.7 percent of the total variation in the data with a standard deviation of the response mean, productive time,of 14.0 percent. An overall F value of 139.6 with 5 degrees of freedom in the numerator and 98 degrees

TABLE B-2

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS
ATLANTA, GEORGIA - AUGUST 18-22, 1969

Operator	Variable						R_2 Percent variation explained
	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway	X_4 Distance vehicle to storage	X_5 Route distance per load	X_0 Constant term	
ATT_1			(Regression analysis not applied)				
ATT_2			(Regression analysis not applied)				
ATT_3	*0.90	0.18	0.014	0.058	6.94	-1.65	94.8
ATT_4	*1.09	0.27	0.019	0.039	5.14	-3.05	85.2
All Trash Taxis	*1.06	0.25	0.019	0.047	4.81	-2.69	87.7
ATM_1	0.20	0.37	-	0.195	*3.55	-0.34	92.9
ATM_2	0.63	*0.12	0.090	0.178	4.06	-10.10	97.4
All Trashmobiles	0.39	0.14	0.021	0.059	*4.99	1.40	91.6

*Variable most highly correlated with productive time.

of freedom in the denominator was obtained. Therefore, the five variables included in the model were significant in explaining productive time. The values of the coefficients for the regression model variables for operators ATT_3, ATT_4 and all Trash Taxis were very similar, with X_1, number of dwelling units serviced per load, being the most highly correlated variable to productive time (Table B-2). Due to this similarity, more confidence can be attributed to the variables used in the regression model. The utility and degree of accuracy of this model can be illustrated by comparing its result to the values observed in the field investigation.

The model can be used to predict the productive time required to make a complete load with the Trash Taxi using the five regression model variables. Productive time is converted to total elapsed time for the load by dividing by the percent productive time (Table B-4). The average values of the variables observed during the study were used: (Table B-3).

Fraction productive time = 87.9 percent

X_1 = number of dwelling units per load = 8
X_2 = number of items per load = 16
X_3 = average distance of vehicle up driveway = 100 ft
X_4 = average distance from vehicle to storage = 30 ft
X_5 = route distance of the satellite vehicle = 0.35 miles

TABLE B-3

AVERAGE VALUES FOR SATELLITE VEHICLE COLLECTION VARIABLES
ATLANTA, GEORGIA, AUGUST 18-22, 1969

		Variable						
Driver	Satellite vehicle loads observed	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway (ft)	X_4 Distance vehicle to storage (ft)	X_5 Route distance per load (mile)	D_{ss} Distance street to storage (ft)	Y Productive time per load (min)
ATT_1	3	10	14	40	40	0.50	90	16.4
ATT_2	6	10	17	50	50	0.65	90	19.3
ATT_3	37	8	15	90	30	0.40	120	14.1
ATT_4	58	8	17	120	30	0.30	140	15.3
All Trash Taxis	104	8	16	100	30	0.35	130	15.1
ATM_1	11	10	17	70	20	0.70	90	14.2
ATM_2	10	15	21	60	40	0.90	100	17.9
All Trashmobiles	21	12	19	70	30	0.80	90	16.0

TABLE B-4

SATELLITE VEHICLE OPERATOR ACTIVITY ANALYSIS
ATLANTA, GEORGIA, AUGUST 18-22, 1969

Collector	Total minutes observed	Percent of total time		
		Productive	Unloading	Other
ATT_1	49.3	68.4	8.0	23.6
ATT_2	115.5	83.7	7.1	9.2
ATT_3	520.0	89.5	9.1	1.4
ATT_4	886.3	88.9	8.6	2.5
All Trash Taxis	1571.1	87.9	8.6	3.5
ATM_1	156.6	92.2	7.8	0.0
ATM_2	178.8	92.2	6.4	1.4
All Trashmobiles	335.4	92.2	7.0	0.8

Substituting these values into the regression model:

$$\text{Productive time} = -2.69 + 1.06(8) + 0.25(16) + 0.019(100) + 0.047(30) + 4.81(0.35)$$

Productive time = 14.8 min

$$\text{Elapsed time} = \frac{14.8}{.879} = 16.8 \text{ min.}$$

Actual average productive time per load* = 15.1 min

Actual average total time per load = 17.2 min

The predicted productive time required per load is 2 percent below the actual time recorded. Two Trash Taxis working together collect from 16 dwelling units in 17.2 min.

Trashmobile Collection Operational Analysis. Twenty-one data points on Trashmobile operations were obtained during the field study in Atlanta. Stepwise regression techniques were applied to the data for each operator individually as well as to both operators together. The best mathematical model for the two Trashmobile operators in Atlanta is (Table B-2)

$$Y_P = 1.40 + 0.39X_1 + 0.14X_2 + 0.021X_3 + 0.059X_4 + 4.99X_5$$

where Y_P = productive collection per satellite vehicle load, in minutes

X_1 = number of dwelling units serviced per load

X_2 = number of items collected per load

X_3 = average distance that the satellite vehicle goes up each dwelling unit driveway, in feet

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*Table B-3.

X_4 = average distance from satellite vehicle to storage point, in feet

X_5 = route distance of satellite collection vehicle per load, in miles

This equation was able to explain 91.6 percent of the total variation in the data, and the standard deviation of the residuals was 9.4 percent of the response mean, Y_P. An overall F value of 32.9 with 5 degrees of freedom in the numerator and 15 degrees of freedom in the denominator was obtained. These five variables were significant in explaining the productive time necessary for collection by a Trashmobile operation. The coefficients of the variables in the models for the individual operators were all of the same order of magnitude (Table B-2). The most highly correlated variable to productive time for the two operators together is X_5, route distance per load. The number of items per load, X_2, was the most significant variable for operator ATM_2.

The Trashmobile regression model can be tested for accuracy similarly to the Trash Taxi by using average values for the variables in the regression model (Table B-3).

X_1 = 12 dwelling units

X_2 = 19 items

X_3 = 70 ft

X_4 = 30 ft

X_5 = 0.80 miles

Percent productive time is 92.2 (Table B-4).

Substituting the above values into the regression model:

$$\begin{aligned}\text{Productive time per load} &= 1.40 + 0.39(12) + 0.14(19) \\ &\quad + 0.021(70) + 0.059(30) + 4.99(0.80) \\ &= 16.0 \text{ min}\end{aligned}$$

Actual productive time per load observed[*] = 16.0 min

The predicted productive time required per average load agrees perfectly with the actual productive time observed. To account for unloading and other time inherent to the operation, the actual total elapsed time per load is $\frac{16.0}{.922}$ or 17.4 min per load. Therefore, two Trashmobiles working together collect 24 dwelling units per 17.4 min.

Packer Truck Drivers Operational Analysis.

The packer truck drivers did not do enough collection to apply regression techniques to their activity. Two of the three drivers observed did not collect at all. The third only collected 4.7 percent (Table B-5) of the time he was observed. The three drivers spent over three-quarters of their time waiting in their trucks while the satellite vehicles collected. Only 23 percent of the driver's time was utilized in contributing to collection route completion.

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[*] Table B-3

TABLE B-5

PACKER DRIVER ACTIVITY ANALYSIS
ATLANTA, GEORGIA - AUGUST 18-22, 1969

Driver	Date	Miles per driving hour	Percent of total time				
			Assisting	Collecting	Driving	Waiting	Other
$AL20_1$	8/18	7.0	9.1	0.0	6.1	83.5	1.3
	8/19	8.2	4.6	0.0	20.9	74.1	0.3
	8/20	4.4	4.7	0.0	10.9	84.3	0.0
	8/21	7.7	4.0	0.0	18.4	76.6	0.1
$AL20_2$	8/22	10.0	7.0	0.0	20.3	72.3	0.4
$AL20_3$	8/20	6.0	17.2	4.7	7.8	54.2	16.1
All drivers	8/18-22	8.1	7.0	0.3	14.7	76.3	1.7

System Cost Analysis

The daily costs of the Trash Taxi and Trashmobile crews were calculated separately due to the distinct differences in their operation and efficiency. All costs, with the exception of the Trash Taxi operating costs, were provided by the Sanitary Division of the City of Atlanta.

Trash Taxi Crew Daily Costs. The costs associated with any satellite vehicle crew are labor wages and fringe benefits, equipment operation and depreciation, and overhead. Equipment operation includes repairs and maintenance in addition to direct operating costs. Operating costs were not available for the Trash Taxi since it was studied during its first week of operation. Operating costs are therefore based on estimates by the manufacturer. Employee fringe benefits were estimated to be 15 percent of wages and the overhead was estimated to be one-sixth of the total crew cost. The costs are expressed in dollars per day.

Labor

2 - satellite vehicle operators at \$19.10 per day + 15 percent fringe benefits	= \$43.92
1 - packer truck driver at \$20.75 per day + 15 percent fringe benefits	= \$23.86
Total labor	= \$67.78

Satellite vehicle operation and depreciation

Operation

2 - Trash Taxis at $1,200 per year = $ 9.22

Depreciation

2 - Trash Taxis, $2,711 new, 4 year life = $ 5.20

Total operation and depreciation = $14.42

Packer truck operation and depreciation

Operation

1 - 20 cu yd Loadmaster at $1,420 per year = $ 5.46

Depreciation

1 - 20 cu yd Loadmaster, $12,059 new, 5 year life = $ 9.28

Total operation and depreciation = $14.74

Overhead

Overhead costs were not available and therefore were estimated to be 20 percent of all other costs.

Overhead cost = 0.20(67.78 + 14.42 + 14.74) = $19.39

Total crew cost

The total daily cost for a Trash Taxi crew in Atlanta is $116.33

Annual Collection Cost Per Dwelling Unit. The annual cost for twice weekly collection for the average dwelling units observed in Atlanta can be determined by multiplying crew cost by crew efficiency. The crews observed during the study spent an average of 6.5 hr per day in the actual process of collection. Therefore the true cost of the Trash Taxi crew is $116.33 per 6.5 hr or approximately $18.00 per hr. The crew efficiency is defined as the number of dwelling units (d.u.) the crew is able to service in 1 hr. The Trash Taxi crew serviced an average of 16 dwelling units per 17.2 min during the study, or 56 dwelling units per hour. The annual collection cost per dwelling unit is then:

$18.00/hr x 1 hr/56 d.u. x 104 collections/d.u./yr = $33.50/yr

Collection Cost Per Ton. The residential waste generation rate for the study area was determined by weighing all of the wastes collected during the field study (Table B-6).

The collection cost per ton was calculated by multiplying the crew cost per hour by the number of hours required per ton collected by the crew. The amount of waste collected per hour by the Trash Taxi crew was:

56 d.u./hr x 3.18 persons/d.u. x 2.4 lb/person/day x 3.5 days = 1,500 lb/hr

The collection cost per ton was:

$18.00/hr x 1 hr/1,500 lb x 2,000 lb/ton = $24.00/ton

TABLE B-6

RESIDENTIAL SOLID WASTE GENERATION
ATLANTA, GEORGIA, AUGUST 18-22, 1969

Date	Weight (lbs)	Services	Lb/capita/day
8/18	5,900	174	2.7
8/21	7,360	347	2.2
Total	13,260	521	2.4

Trashmobile Crew Daily Costs. The labor and packer truck costs for the Trashmobile crews are the same as those for the Trash Taxi crews. Satellite vehicle operation and depreciation costs and overhead costs must be calculated for the Trashmobile crews.

Satellite vehicle operation and depreciation

Operation

2 - Trashmobiles each at $727 per year = $ 5.58

Depreciation

2 - Trashmobiles, $2,400 new, 4 year life = $ 4.62

Total operation and depreciation = $10.20

Overhead

Overhead cost is assumed to be 20 percent of all other costs.

Overhead cost = 0.20 (67.78 + 10.20 + 14.74) = $18.54

Total crew cost

The total daily cost of the Trashmobile crew described is = $111.26

Annual Collection Cost Per Dwelling Unit. The Trashmobile true crew cost was $111.26 per 6.5 hrs or approximately $17.00 per hour. Two Trashmobile operators were each able to service an average of 12 dwelling units per 17.4 min. The total crew efficiency was

24 dwelling units per 17.4 min or 83 dwelling units per hour. The annual collection cost per dwelling unit is:

$$\$17.00/\text{hr} \times 1\ \text{hr}/83\ \text{d.u.} \times 104\ \text{collections/d.u./yr} \cong \$21.50/\text{yr}$$

Collection Cost Per Ton. The amount of waste collected per hour by the Trashmobile crew observed was:

$$83\ \text{d.u./hr} \times 3.18\ \text{persons/d.u.} \times 24\ \text{lb/person/day} \times 3.5\ \text{days} = 2{,}200\ \text{lb/hr}$$

The collection cost per ton becomes:

$$\$17.00/\text{hr} \times 1\ \text{hr}/2{,}200\ \text{lb} \times 2{,}000\ \text{lb/ton} \cong \$15.50/\text{ton}$$

Satellite Vehicle Collection vs. Conventional Collection

It is important to determine if the satellite vehicle collection systems in Atlanta are as efficient and economical as conventional walking collectors could be in their place.

A regression model which estimates the productive time required for a walking collector to service any number of dwelling units with some particular characteristics can be used to calculate their efficiency. This regression model is:

$$^{*}C = 0.18 - 0.12W_1 + 0.12W_2 + 0.24W_3 + 0.005W_4$$

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[*] Appendix A

where C = productive time, in minutes, to service W_1 dwelling units

W_1 = the number of dwelling units to be serviced

W_2 = total number of items to be collected from W_1 dwelling units

W_3 = total number of round trips to the truck made by the walking collector while servicing W_1 dwelling units

W_4 = total distance, in feet, walked by the collector while servicing W_1 dwelling units

Separate comparisons were made of the walking collectors with the Trash Taxi crews and the Trashmobile crews.

First, the time required by a walking collector to service eight dwelling units with characteristics identical to the average dwelling units serviced by the Trash Taxis was estimated (Table B-3).

W_1 = eight dwelling units

W_2 = two items per dwelling unit x eight dwelling units = 16 items

W_3 = one trip per three items* x 16 items = 5.33 trips

$$W_4 = \left[45 + 2.55 \text{ (average street to storage)}\right] W_1^{*}$$

$$= \left[45 + 2.55(130)\right] 8 \cong 3{,}010 \text{ ft}$$

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*Appendix A

Substituting into the walking collector regression model:

$$C = 0.18 - 0.12(8) + 0.12(16) + 0.24(5.33) + 0.005(3{,}010)$$
$$= 17.47 \text{ min of productive time}$$

Since the average walking collector is productive 85 percent of the total time on the collection route, the total time required for him to service these eight dwelling units would be $\frac{17.47}{0.85}$, or 20.5 min.

The average total time required by a Trash Taxi operator to service these same dwelling units was 17.2 min. Thus, the use of Trash Taxis in this area is theoretically 19.1 percent more efficient than the use of walking collectors.

The total cost of a crew with two walking collectors, a packer truck and a packer driver in Atlanta is \$99.02 per day. Since the crews are on the collection route an average of 6.5 hr per day, the true hourly cost per collection hour are approximately \$15.00 per hr. The walking crew services a total of 16 dwelling units each 20.5 min. The annual collection cost per dwelling unit is then:

$$\$15.00/\text{hr} \times \frac{20.5 \text{ min}}{16 \text{ dwelling units}} \times 1 \text{ hr}/60 \text{ min} \times 104 \text{ collections/yr} = \$33.50/\text{yr}$$

The cost for equivalent service by the Trash Taxis is also \$33.50 per dwelling unit per year. The walking collection system is theoretically just as economical as the Trash Taxi system.

The time required by a walking collector to service 12 dwelling units with characteristics identical to the average dwelling unit serviced by the Trashmobiles in Atlanta also was estimated.

W_1 = 12 dwelling units

W_2 = 1.6 items per dwelling unit x 12 dwelling units = 19 items

W_3 = one trip per three items[*] x 19 items = 6.33 trips

W_4 = 45 + 2.55 (average street to storage[+]) W_1[*]

= 45 + 2.55(90) 12 = 3,290 ft

Substituting into the walking collector regression model:

$$C = 0.18 - 0.12(12) + 0.12(19) + 0.24(6.33) + 0.005(3,290)$$

= 18.99 min of productive time

Since the average walking collector is only 85 percent productive, the total time required would be $\frac{18.99}{0.85}$, or 22.3 min.

The Trashmobile operators averaged 17.4 min to service 12 dwelling units with identical characteristics. Therefore, the average Trashmobile operator is theoretically 28 percent more efficient than the average walking collector when servicing these dwelling units.

[+] Table B-3

[*] Appendix A

The walking collector crew costs \$15.00 per hr. This crew theoretically services a total of 24 dwelling units each 22.3 min. The annual collection cost per dwelling unit would then be:

$$\$15.00/\text{hr} \times \frac{22.3 \text{ min}}{24 \text{ dwelling units}} \times 1 \text{ hr}/60 \text{ min} \times 104 \text{ collections/yr} = \$24.00/\text{yr}$$

The annual collection cost using Trashmobiles was \$21.50 per dwelling unit in this area. Theoretically, waste collection by Trashmobile is 12 percent more economical than the conventional waste collection method.

General Comments and Conclusions

The Trash Taxis and Trashmobiles observed were operated in the north-east section of Atlanta. This area has a varied terrain with many hills and steep driveways. The homes serviced were old large high-income family homes, unlike housing development areas of today. The houses were located on large lots with very long driveways. The average street to storage distance for dwelling units served by the Trash Taxis was 140 ft as opposed to only 90 ft for residences served by the Trashmobiles observed.

The satellite vehicle operators used 50 gal rubber barrels to transfer the waste from the dwelling unit storage point to their vehicles. The average distance for operators of both types of vehicles was about 30 ft. The average distance for all cities studied was only 15 ft. Easier accessibility to the waste would result in an increased crew efficiency for the collectors.

The low number of items per residence, approximately 1.7, was due to the separate collection of all garden wastes. Assuming garden wastes to be 30 percent of total wastes during the summer, combined collection would decrease crew efficiency by approximately 10 percent. Eighty-seven percent of the items collected during the study were stored in acceptable standard containers (Table B-7). The percentage of miscellaneous items was lower than in other study areas.

The regression models illustrate the large difference in efficiency between the Trashmobiles and the Trash Taxis in Atlanta. Under identical conditions, the Trashmobile was able to service 50 percent more dwelling units per elapsed hour than the Trash Taxi. Since this was the first week of operation for the Trash Taxi and the Trashmobile has been in operation for 3 yr, some discrepancy is naturally expected. However, this fact cannot account for the entire difference. The lower crew efficiency of the Trash Taxi crew was also caused by particular deficiencies in the satellite vehicle.

The major problem which the Trash Taxi operators encountered during the vehicle's first week of operation was its inadequate power to climb steep driveways. Many times the packer truck driver had to help push the vehicle out of a driveway in which it had become stuck. This lack of power is partly due to the

TABLE B-7

ITEM CLASSIFICATION
ATLANTA, GEORGIA, AUGUST 18-22, 1969

Date	Total items collected	Percent of total	
		Standard containers	Miscellaneous
8/18	412	83.1	16.9
8/19	380	89.0	11.0
8/20	265	77.0	23.0
8/21	619	90.5	9.5
8/22	389	90.5	9.5
Week	2,065	87.0	13.0

provision of a hydraulic power inadequate for the size of the vehicle and, the restriction of the vehicle's maximum speed to 28 mph. In addition to lack of power, the vehicles suffered steering column failures, frequent stalling, hydraulic fluid leakage, gasoline leakage and emergency brake failure during the one week study. The leakage of hydraulic fluid damaged asphalt driveways of customers in addition to being a mechanical problem. Unless several corrections are made and the vehicle can produce more power, it cannot compete with the more efficient Trashmobile in the City of Atlanta.

The average unloading times for the Trash Taxi and Trashmobile were 1.5 and 1.2 min respectively. Both of these times were less than the average unloading time for Cushman scooters. Twenty yd^3 Loadmaster packer trucks were used on all routes observed. The Loadmaster has a hopper capacity of 1.5 cu yd and two compaction cycles were normally needed to accommodate the wastes from the satellite vehicles, thus creating high unloading times.

APPENDIX C

COLUMBIA, SOUTH CAROLINA
FIELD STUDY - JUNE 24-27, 1969

Columbia, the capital of South Carolina, is a city of 98,000 persons (Table C-1) located in the south central area of the state. The city lies on flat terrain, but is surrounded by hills. The summer climate of Columbia is very hot and humid and temperature and humidity readings of 100 are common during this season.

The Department of Sanitation has had the responsibility of collecting and disposing of all residential solid wastes in the City since November, 1967. Prior to this date waste collection had been the responsibility of a private company on contract with the city. In the transition, the City inherited poor equipment and the problems of the contractor who was forced out of business due to unsatisfactory service.

The Department of Sanitation presently provides once weekly curbside collection of "trash" (tree trimmings and grass) and twice weekly backyard collection of "garbage" (non-garden wastes) for the 26,000 dwelling units in the City (Table C-1).

There are 24 residential "garbage" collection routes. Cushman satellite vehicles are presently used on four of these routes in the southeastern section of the City. The City also uses container trains (a Scout and three container trailers) on six routes. The Department inherited 19 Cushman scooters from the private contractor, but only 13 are operational and only eight

TABLE C-1

DESCRIPTION OF COLUMBIA, SOUTH CAROLINA

Population		98,000 (Est. 1/1/69)[*]
Dwelling units		26,600 (est. 1/1/69)*
Persons per dwelling unit		3.68
Land area		20.6 sq mi[+]
Population density	(City)	4,800 persons/sq mi
	(Study area)	3,600 persons/sq mi
Dwelling density	(City)	1,300 dwelling units/sq mi
	(Study area)	970 dwelling units/sq mi
Miles of streets		560[+]
Dwelling units per street mile		50 dwelling units/mile
	(Study area)	70 dwelling units/mile

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*From 1969 Rand-McNally Commercial Atlas and Marketing Guide.

[+] Engineering Department, City of Columbia, South Carolina.

are actually in use. Most of the satellite vehicles are in various states of disrepair (Figure C-1), due to the long lead time required on major part orders from the manufacturer. The Department suffers from high absenteeism among the employees and is unable to find enough employees with driver's licenses to operate the satellite collection vehicles.

The four crews with Cushman satellite vehicles each consist of two men with satellite vehicles, two walking collectors with plastic barrels on wheels, and a packer truck with a driver.

FIELD STUDY ANALYSIS

The field study was conducted June 24-27, 1969. During the four day study two satellite collection vehicle crews were observed in the eastern section of the City. This area was characterized by medium to high income houses on flat terrain with long driveways. One crew used Cushman satellite vehicles with extended hydraulic pumps to be used in conjunction with a side loading packer truck. The other crew operated Cushman satellite vehicles with flat beds carrying four 50-gal plastic barrels. A total of 46 data points were obtained on five individual satellite vehicle operators.

Satellite Vehicle Collection Operational Analysis

Stepwise regression techniques were applied to the satellite vehicle data in an attempt to explain the productive time per

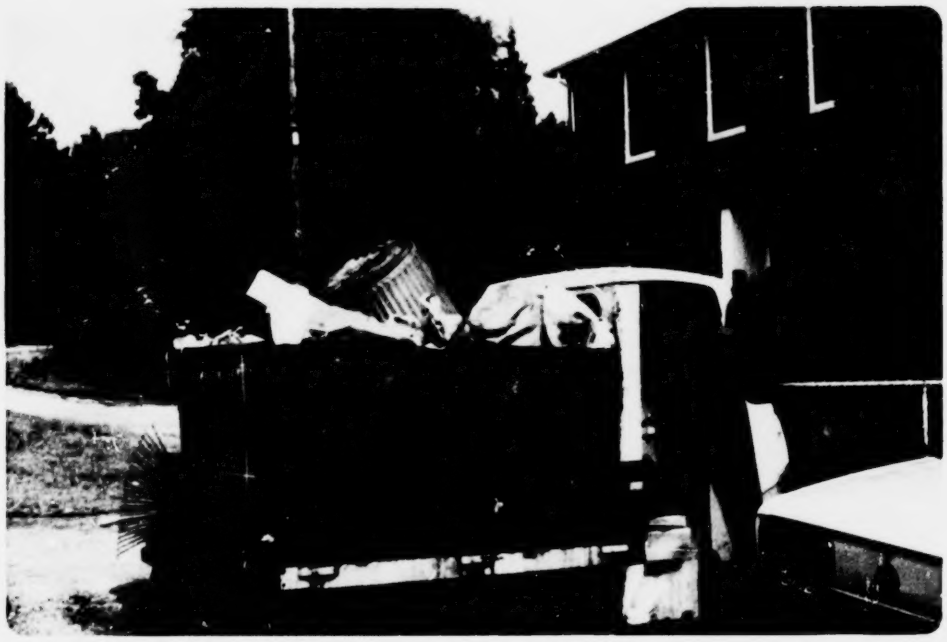

Figure C-1. Cushman satellite waste collection vehicle with flat-bed used in Columbia, S. C.

satellite vehicle trip using the five variables recorded during the study. Individual regression analyses were made for two operators, one using a flatbed vehicle, and one using a dump vehicle, and also on all of the data combined. The regression model which best described the productive time for all the data combined was (Table C-2):

where $Y_p = 5.42 + 1.10\ X_1 + 3.02\ X_5$

Y_p = productive time per satellite vehicle load

X_1 = number of dwelling units serviced per load

X_5 = route distance of the satellite vehicle per load, in miles

This equation was able to explain 71.7 percent of the total variation in the data and the standard deviation of the residuals was 20.2 percent of the response mean, productive time. The variable most highly correlated to productive time was X_1, the number of dwelling units serviced per satellite vehicle load. Three of the variables recorded during the study were not significant in explaining productive time in this model. The models for the two individual operators included as many as five variables and their coefficients were of the same order of magnitude as the combined model.

The regression model was tested for prediction accuracy by comparing it to the actual field results for a particular situation. The average variable values observed in the study (Table C-3)

TABLE C-2

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS
COLUMBIA, SOUTH CAROLINA - JUNE 24-27, 1969

Operator	Variable						R_2 Percent variation explained
	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway	X_4 Distance vehicle to storage	X_5 Route distance per load	X_0 Constant term	
CCF_1	*0.93	0,34	----	----	3.50	-2.32	95.0
CCD_1	0.53	0.37	0.216	-0.185	*3.46	-2.42	95.7
Combined	*1.10	----	----	----	3.02	55.42	71.7

were used in this case. Productive time was converted to the total elapsed time per load using the fraction of productive time for all satellite vehicles observed in Columbia (Table C-4).

The average variable values were: (Table C-3)

X_1 = number of dwelling units serviced per load = 11

X_5 = route distance of the satellite vehicle per load = 1.55 miles

Percent productive time = 82.3 percent

Substituting these values into the regression model:

$$\text{Productive time} = 5.42 + 1.10\ (11) + 3.02\ (1.55) = 22.2 \text{ min per load}$$

The actual average productive time observed during the field study was 22.6 min per load.

The predicted productive time per load is therefore 1.8 percent lower than the actual observed time. The actual total elapsed time per load was $\frac{22.6}{.823}$ or 27.5 min due to the normal unloading time and associated other time. Two satellite vehicles working together were able to service 22 dwelling units in 27.5 min for the average conditions observed in Columbia.

Packer Truck Driver Operational Analysis

The packer truck drivers were required to remain in their trucks due to faulty emergency brakes, which are presently being replaced by air lock brakes. The amount of collection done by the packer truck drivers was insignificant. The drivers spent

TABLE C-3

AVERAGE VALUES FOR SATELLITE VEHICLE COLLECTION VARIABLES
COLUMBIA, SOUTH CAROLINA - JUNE 24-27, 1969

Driver	Satellite vehicle loads observed	Variable						
		X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway (ft)	X_4 Distance vehicle to storage (ft)	X_5 Route distance per load (mile)	D_{ss} Distance street to storage (ft)	Y Productive time per load (min)
CCF_1	16	8	19	60	30	1.15	90	15.8
CCD_1	11	15	22	50	30	1.75	80	25.5
Combined	46	11	21	50	30	1.55	80	22.6

TABLE C-4

SATELLITE VEHICLE OPERATOR ACTIVITY ANALYSIS

COLUMBIA, SOUTH CAROLINA - JUNE 24-27, 1969

Operator	Total Minutes Observed	Percent of Total Time		
		Productive	Unloading	Other
CCF_1	293.8	77.1	11.5	11.4
CCF_2	225.9	81.6	7.5	10.9
CCD_1	343.6	76.7	5.7	17.6
CCD_2	279.0	86.0	10.5	3.5
CCD_3	122.8	88.0	8.1	3.9
Combined	1295.1	82.3	8.3	9.4

over 60 percent of their total time waiting at or in the packer truck (Table C-5). Based on driver activity in other cities, all of this time could be spent more constructively either collecting or assisting the satellite vehicles in the unloading process. A recently adopted department policy has given the drivers the responsibility of directing and coordinating the satellite vehicle efforts with those of the walking collectors to achieve better waste collection efficiency.

System Cost Analysis

The following daily costs for satellite vehicle collection crews were based on figures obtained from the Superintendent of Sanitation in the City of Columbia for the period of March 1968 through February 1969. For study comparison purposes, the two walking collectors in Columbia's crews were ignored and the crew was divided as two satellite vehicle operators and the packer truck driver.

Daily Crew Costs

The costs of a satellite vehicle waste collection crew are labor, equipment operation and depreciation, and overhead. Equipment operation includes repairs and maintenance in addition to direct operating costs. The following costs are expressed in dollars per day.

Labor

2 satellite vehicle operators at $12.30/day
+ 15 percent fringe benefits = $28.30

TABLE C-5

PACKER TRUCK DRIVER ACTIVITY ANALYSIS

COLUMBIA, SOUTH CAROLINA - JUNE 24-27, 1969

			Percent of Total Time				
Driver	Date	Miles per driving hour	Assisting	Collecting	Driving	Waiting	Other
CG20	6/24	8.3	0.0	0.0	14.9	72.1	13.0
	6/25	9.4	0.8	0.0	12.0	83.6	3.6
CY30	6/26	6.1	10.8	0.2	20.2	57.1	11.7
	6/27	4.1	10.6	6.8	27.8	46.3	8.5
Combined	6/24-27	6.2	6.5	1.5	19.4	61.8	10.8

1 packer truck driver at \$14.90/day + 15 percent fringe benefits	= \$17.15
Total labor cost	\$45.45

Satellite Vehicle Operation and Depreciation

Operation	
2 satellite vehicles each at \$410/vehicle/yr	= \$ 3.20
Depreciation	
2 satellite vehicles, \$2,600 new, 4-yr life	= \$ 5.00
Total operation and depreciation	\$ 8.20

Packer Truck Operation and Depreciation

Operation	
1 - 20 cu yd Garwood "700" at \$1,500/yr	= \$ 5.78
Depreciation	
1 - 20 cu yd Garwood, \$15,000 new, 8-yr life	= \$ 7.21
Total operation and depreciation	\$12.99

Overhead

Overhead costs were unable to be obtained and were therefore estimated to be 20 percent of all other crew costs.

Overhead Costs = .20 (45.45 + 8.20 + 12.99) = \$13.33

Total Crew Costs

The total cost per day for this average satellite vehicle crew is \$79.97

Annual Collection Cost per Dwelling Unit

The annual cost to the average dwelling unit observed in Columbia for twice weekly collection was determined by multiplying the crew efficiency by the crew cost rate. During the field investigation, the crews observed averaged 5.5 hr per day in the actual process of collection. The true crew cost rate is then \$79.97/day x 1 day/5.5 hr or approximately \$14.50/hr. The crew efficiency was 22 dwelling units per hr. The annual cost per dwelling unit is then:

$$\frac{\$14.50}{\text{hr}} \times \frac{1\ \text{hr}}{48\ \text{d.u.}} \times 104\ \text{collections/d.u./yr} \cong \$31.50$$

Collection Cost Per Ton

The residential waste generation rate for Columbia was not able to be determined due to the unavailability of truck scales at the time of the study. The national residential waste generation rate of 3.0 lb/capita/day was assumed, and the collection cost per ton was calculated. The amount of waste collected per hour by the crew would be:

$$48\ \text{d.u./hr} \times 3.68\ \text{persons/d.u.} \times 3.0\ \text{lb/person/day} \times 3.5\ \text{days between collecting} = 1{,}850\ \text{lb/hr}$$

The collection cost per ton is then:

$$\$14.50/\text{hr} \times 1\ \text{hr}/1{,}850\ \text{lb} \times 2{,}000\ \text{lb/ton} = \$15.50/\text{ton}$$

Satellite Vehicle Collection vs. Conventional Collection

The time and costs required to service the dwelling units observed in Columbia by walking collectors was estimated and compared with the time and costs using satellite vehicles. To facilitate the calculation, the time required to service 11 dwelling units, the average number per satellite vehicle load was used in the calculations. Using average values (Table C-3):

W_1 = 11 dwelling units

W_2 = 1.9 items/dwelling unit x 11 dwelling units $\cong$ 21 items

W_3^* = 1 trip/3 items x 21 items = 7 trips

$W_4^* = \left[45 + 2.55 \text{ (average street to storage)}\right] W_1 \cong 2{,}740$ ft

Substituting into the regression model for conventional collection (Appendix A):

$$C = 0.18 - 0.12(11) + 0.12(21) + 0.24(7) + 0.005(2740)$$

$$C = 16.7 \text{ minutes of productive time}$$

Walking collectors are productive approximately 85 percent of the time which they spend on the route (Appendix A). The total time for one walking collector to service 11 dwelling units then becomes:

$$\frac{16.7}{.85} \text{ or } 19.6 \text{ minutes}$$

---

[*] Appendix A

The average satellite vehicle operator in Columbia required 27.5 min to service the same number of dwelling units. Use of average walking collectors in Columbia would theoretically increase collection efficiency by 40 percent.

The cost of a crew with two walking collectors and a packer truck with driver would be equal to that of a satellite vehicle crew minus satellite vehicle depreciation, operation and overhead costs. This cost is $79.97 - 1.20(8.20) = $70.13 per day. Since the crews actually collect for 5.5 hr on the route per day, the true cost is approximately $12.00 per collection hour. The two walking collectors together collect 22 dwelling units per 19.6 min or 67 dwelling units per hr. The packer truck driver does not participate in collection. The annual collection cost per dwelling unit is then:

$$\$12.00/\text{hr} \times 1\ \text{hr}/67\ \text{d.u.} \times 104\ \text{collections/d.u./yr} \cong \$18.50$$

The collection service cost using walking collectors is theoretically only 58 percent of the same service cost using satellite vehicle collection.

OPERATIONAL COMMENTS

There were several constraints which severely limited the collection efficiency of the satellite vehicle operators in Columbia. The primary hindrance was the hot weather during the study period. The temperature and humidity readings approached 100 on all four days of the study. The operators had to pace themselves to avoid heat exhaustion, and dehydration, which could result in severe sickness or death.

The poor mechanical condition of the satellite vehicles was another factor adversely affecting the efficiency of waste collection. Frequent engine stalls and tire punctures were observed during the study. Frequently the vehicles did not start in the morning and delayed the operators from getting to their routes.

General thoughtlessness on the part of the residents contributed to the inefficiency of the system. Accessability to the waste storage area was imbedded by cars blocking driveways, closed fence gates and menacing dogs. This resulted in an increased walking distance for the operators from their vehicles to the waste storage point. The average distance observed was 30 ft, twice the average walking distance observed in the other five areas studied. The satellite vehicle operators used 50 and 60 gal plastic barrels to carry the wastes from the storage point to the satellite vehicle.

The satellite vehicle unloading times observed were the longest of the six areas studied. The average time required for unloading the extended hydraulic dumps into a 32 yd side-loading packer was 2.5 min (Figure C-2). The flatbed vehicles had an average unloading time of 2.1 min when unloading into a 20 cu yd Garwood 700 rear-loading packer with a 1-1/2 cu yd hopper. Two packing cycles of the Garwood were required to accommodate each satellite vehicle waste load of 1-1/4 cu yd. Use of a packer with a larger hopper could reduce unloading time by 50 percent or more. Packer trucks with rear loaders were currently on order to replace all side-loading packers in Columbia.

Two significant improvements could be made in the satellite vehicle collection systems observed in Columbia. Better coordination between the satellite vehicle operators would eliminate the frequent duplication of services. The duplication of effort observed during the study occurred for 34 dwelling units or 6.5 percent of the total number of dwelling units serviced. This amounts to 3/4 of a dwelling unit extra per satellite vehicle load.

The second improvement would be to reduce the route distance traveled by the satellite vehicles during each load. The average distance observed during the study was 1.55 miles, over three times the average for the other five study areas. By working closer to the packer truck this distance could be reduced to approximately 0.50 miles and increase collection efficiency significantly.

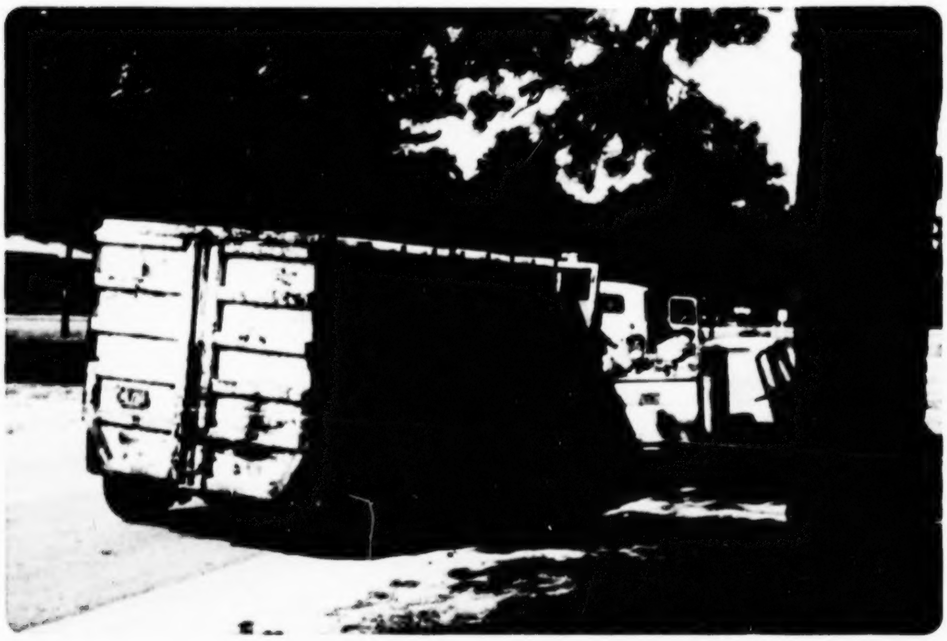

Figure C-2. Unloading satellite vehicle with extended hopper into side-loading packer.

The prediction model was used to quantify the amount of time wasted by the two system deficiencies discussed above. The time required to service the 0.75 duplicate dwelling unit and to travel the extra 1.05 route miles was:

$$\text{Wasted time per load} = 5.42\ \frac{0.75}{11} + 1.10\ (0.75\ \text{duplicate dwelling units}) + 3.02\ (1.05\ \text{extra route miles}) = 4.4\ \text{min}$$

This wasted time was approximately 20 percent of the average productive time required per load during the study. Thus, system improvements in these two areas could improve the efficiency of the total system by as much as 20 percent.

APPENDIX D

KNOXVILLE, TENNESSEE

FIELD STUDY, JULY 14-18, 1969

Knoxville is a city of 187,000 people located 40 miles northeast of the Great Smoky Mountains in Tennessee (Table D-1). The terrain of the City is varied with steep hills common in many areas.

Sanitary Disposal Company provides residential waste collection on contract with the City to approximately 50 percent of the population. The Company services the entire area surrounding the central business district on a once per week collection basis. The collection charge is $2.50 per dwelling unit per month. The City provides collection of garden wastes to these same areas once weekly.

Sanitary Disposal Company created the Trashmobile, an International Scout chassis with a 1-1/2 cu yd dump, to solve labor problems, reduce costs and increase efficiency in the hilly areas of Knoxville. Scout trucks are now being replaced with Datsuns as they appear to require less maintenance than the Scout. Sanitary Disposal operates 2 to 3 Trashmobiles on each of 12 collection routes in the City of Knoxville. The Company also has additional private routes in annexed areas of Knox County at a cost of $2.50 per month for once per week collection.

TABLE D-1

KNOXVILLE, TENNESSEE
STATISTICS

Population[+]	187,000 (1/1/69)
Dwelling units[*]	52,330
Persons per dwelling unit	3.57
Land area[*]	77 sq miles
Population density	2,430 persons/sq mile
Housing density	680 houses/sq mile
Miles of street[±]	998
Dwelling units per mile of street	50

[+] From 1969 Rand McNally Commercial and Marketing Atlas

[*] From Advanced Planning Commission, City of Knoxville, Tennessee

[±] From Engineering Department, City of Knoxville, Tennessee

Field Study Analysis

The field study was conducted July 14 through 18 in the very hilly eastern section of the City of Knoxville. Four Trashmobile operators in two different crews were observed during the week. Two collectors used Datsuns and two collectors operated Scouts. The activities of two packer truck drivers were also recorded.

Satellite Vehicle Collection Operational Analysis

Stepwise regression analyses were conducted on the four satellite vehicle operators individually and together (Table D-2). In addition to the regression analyses using five variables, supplemental regressions were made using seven variables. The two extra variables resulted from classifying items as standard containers, 55-gal drums, and miscellaneous items. This analysis was conducted to determine the adverse affects of 55-gal drums on the operator's collection efficiency.

The regression model which best describes the 287 satellite vehicle loads observed in Knoxville, using five variables was (Table D-2):

$$Y_P = + 0.57 + 0.77X_1 + 0.16X_2 + 0.002X_3 + 0.039X_4 + 1.75X_5$$

where Y_P = Productive collection time per satellite vehicle load, in minutes

X_1 = Number of dwelling units serviced per load

X_2 = Number of items collected per load

X_3 = Average distance satellite vehicle goes up each dwelling unit driveway, in feet

TABLE D-2

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS
KNOXVILLE, TENNESSEE - JULY 14-18, 1969

Operator	Variable						R_2 Percent variation explained
	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway	X_4 Distance vehicle to storage	X_5 Route distance per load	X_0 Constant term	
KTS_1	*1.14		0.012	0.022	4.24	0.71	75.3
KTS_2	*0.73	0.16	0.006	0.027	2.17	-0.03	85.6
KTD_1	*0.80	0.19	-	0.057	2.05	0.34	78.1
KTD_2	0.60	*0.29	0.002	-	0.95	-0.07	67.3
Combined	*0.77	0.16	0.002	0.039	1.75	0.57	70.4

*Variable most highly correlated with productive time.

X_4 = Average distance from satellite vehicle to storage point, in feet

X_5 = Route distance of satellite vehicle per load, in miles

This equation was able to explain 70.4 percent of the total variation in the data, and the standard deviation of the residuals was 17.4 percent of the response mean, productive collection time. The most highly correlated variable to productive collection time was the number of dwelling units serviced. The coefficients for each operator are of the same order of magnitude for corresponding variables, with the number of dwelling units being the most highly correlated for three of the four operators observed (Table D-2).

To illustrate the utility and accuracy of the regression model, its results may be compared to the actual field observations. Using the average values of the variables observed in Knoxville (Table D-3), the time required to make one round trip with the satellite vehicle was predicted. To account for unloading time and other time, the productive time must be divided by the fraction of productive time (Table D-4). The average values of the variables for this example were:

X_1 = 6 dwelling units per load

X_2 = 15 items per load

X_3 = 100 ft up each dwelling unit driveway

X_4 = 20 ft from satellite vehicle to storage

X_5 = 0.55 miles route distance

Percent productive time = 87.1 percent

TABLE D-3

AVERAGE VALUES FOR SATELLITE VEHICLE COLLECTION VARIABLES
KNOXVILLE, TENNESSEE - JULY 14-18, 1969

		Variable						
Operator	Satellite vehicle loads observed	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway (ft)	X_4 Distance vehicle to storage (ft)	X_5 Route distance per load (mile)	D_{ss} Distance street to storage (ft)	Y_P Productive time per load (min)
KTS_1	39	6	16	60	20	0.40	80	10.6
KTS_2	78	6	14	80	20	0.45	90	8.7
KTD_1	85	6	14	100	20	0.50	110	9.7
KTD_2	85	7	18	130	10	0.70	130	10.1
Combined	287	6	15	100	20	0.55	110	9.7

TABLE D-4

SATELLITE VEHICLE OPERATOR ACTIVITY ANALYSIS KNOXVILLE, TENNESSEE - JULY 14-18, 1969

Operator	Total minutes observed	Percent of total time		
		Productive	Unloading	Other
KTS_1	517.2	80.2	8.5	11.3
KTS_2	764.1	89.1	7.3	3.6
KTD_1	925.0	88.8	8.4	2.8
KTD_2	981.8	87.5	9.2	3.3
Combined	3,188.1	87.1	8.4	4.5

For one satellite vehicle load:

$$\text{Productive time} = + 0.57 + 0.77(6) + 0.16(15) + 0.002(100) + 0.039(20) + 1.75(0.55)$$

Productive time = 9.7 min per load

Total elapsed time $\frac{9.7}{.871} = 11.1$ min per load

Actual average productive time per load = 9.7 min per load

Actual total elapsed time = $\frac{9.7}{.871} = 11.1$ min per load

The predicted productive time required to collect this average load is identical to the actual time observed. Two Trashmobile operators in a crew were able to service 12 dwelling units in 11.1 min.

The regression model for the Trashmobile operation in Knoxville when the items collected were classified into three categories was (Table D-5):

$$Y = 0.59 + 0.71X_1 + 0.22X_{2c} + 0.30X_{2b} + 0.14X_{2m} + 0.028X_4 + 2.04X_5$$

where X_1 = number of welling units per load

X_{2c} = number of standard containers collected

X_{2b} = number of 55-gal drums collected

X_{2m} = number of miscellaneous items collected

X_4 = average distance from the satellite vehicle to the storage point

X_5 = route distance of satellite vehicle, in miles

This equation was able to explain 70.4 percent of the total variation in the data, and the standard deviation of the residuals was 19.8 percent of the response mean. The model coefficients were

TABLE D-5

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS WITH CLASSIFICATION OF ITEMS KNOXVILLE, TENNESSEE

Operator	Variable								R_2 Percent variation explained
	X_1 Dwelling units serviced per load	(X_{2c}) Number of standard containers collected	(X_{2b}) Number of 55 gal drums collected	(X_{2m}) Number of miscellaneous items collected	(X_3) Distance vehicle up driveway	(X_4) Distance vehicle to storage	(X_5) Route distance per load	X_0 Constant term	
KTS_1	1.15	-	-	0.07	0.016	0.026	3.66	0.25	76.1
KTS_2	0.61	0.28	0.60	0.19	0.009	0.033	1.69	1.34	87.8
KTD_1	0.64	0.32	0.24	0.12	-	0.056	1.99	0.62	83.8
KTD_2	0.73	0.41	0.59	0.33	-	-0.068	-	-1.00	61.9
Combined	0.71	0.22	0.30	0.14	-	0.028	2.04	+0.59	70.4

similar to values in the unclassified container model discussed above. The coefficient for variable X_{2b}, number of 55-gal drums, was larger than the coefficients for standard containers and miscellaneous items, indicating the increased time required to collect waste from 55-gal drums. Container classification was extremely important in describing productive time for operators KTO_2 and KTS_2 (Table D-5).

Using the variable values from the first example with container classification, the classified container model was compared to the unclassified container model. The 15 containers serviced per average load included nine standard containers, two 55-gal drums and four miscellaneous items (Table D-6). Substituting into the model:

$$\text{Productive time} = 0.59 + 0.71(6) + 0.22(9) + 0.30(2) + 0.14(4) + 0.03(20) + 2.04(0.55)$$

Productive time = 9.8 min per load

Actual average productive time = 9.7 min per load

Comparing the results of the two models, it can be seen that the regression model without container classification is able to better describe productive time per load than the predictive model with container classification, for this case.

Packer Truck Driver Operational Analysis

Regression analyses were made on the data recorded for the collection activity of the two packer truck drivers observed (Table D-7). Based on 356 data points, the best regression model

TABLE D-6

CONTAINER CLASSIFICATION
KNOXVILLE, TENNESSEE - JULY 14-18, 1969

Operator	Average number of items per load	Classification		
		Standard containers	55-gal drums	Miscellaneous items
KTS_1	16	10	2	4
KTS_2	14	8	2	4
KTD_1	14	8	2	4
KTD_2	18	12	2	4
Combined	15	9	2	4

TABLE D-7

PACKER DRIVER COLLECTION MODEL COEFFICIENTS
KNOXVILLE, TENNESSEE - JULY 14-18, 1969

Driver	Variable				R_2 Percent variation explained
	b_1 Number of dwelling units serviced between truck moves	b_2 Number of items collected	b_3 Average distance truck to storage	b_o Constant term	
$KG25_1$	0.63	*0.30	0.008	-0.29	59.9
$KG25_2$	0.56	*0.34	0.012	-0.98	83.8
Combined	0.57	0.31	0.010	-0.52	71.5

*Variable most highly correlated with productive collection time.

for explaining productive collection time for the two packer truck drivers observed in Knoxville was (Table D-7):

$$T = -0.52 + 0.57b_1 + 0.31b_2 + 0.010b_3$$

where T = Productive collection time required to service b_1 dwelling units between truck moves

b_1 = Number of dwelling units serviced between truck moves

b_2 = Number of items collected from b_1 dwelling units

b_3 = Average distance which the driver walked from truck to storage point, in feet

This model was able to explain 71.5 percent of the variation in the data, and the standard deviation of the residuals was 34.2 percent of the response mean. The model coefficients for the two individual drivers were very similar, with variable b_2, the number of items collected, being the most highly correlated to productive time. The significance of variable b_2 may be attributed to the diversity in the types of containers used in Knoxville, and the corresponding diversity in collection time required.

The packer truck driver collection model may be tested similarly to the satellite vehicle operator model. For this example, average variable values were used (Table D-8). The time devoted to collection by the packer truck drivers in Knoxville was 44 percent of total time (Table D-9).

TABLE D-8

AVERAGE VALUES FOR PACKER TRUCK DRIVER COLLECTION VARIABLES KNOXVILLE, TENNESSEE - JULY 14-18, 1969

Driver	Number of data points	Variables			
		b_1 Number of dwelling units serviced between truck moves	b_2 Number of items **collected**	b_3 Average distance truck to storage	Y_P Productive time (**min**)
$KG25_1$	218	1	3	90	2.0
$KG25_2$	138	2	4	80	2.4
Combined	356	1	3	80	2.2

TABLE D-9

PACKER TRUCK DRIVER ACTIVITY ANALYSIS
KNOXVILLE, TENNESSEE - JULY 14-18, 1969

Driver	Date	Average miles per driving hour	Percent of total time				
			Assisting	Collecting	Driving	Waiting	Other
$KG25_1$	7/14	7.0	22.1	40.9	20.5	12.2	4.3
	7/15	7.4	17.6	44.0	19.4	7.7	11.3
	7/18	6.8	6.8	49.7	9.2	5.2	29.1
$HG25_2$	7/16	5.5	27.1	32.5	19.6	12.5	8.3
	7/17	6.1	16.8	49.3	16.7	8.4	8.8
Combined		6.6	18.1	43.3	17.1	9.2	12.3

b_1 = 1 dwelling unit collected between each truck move

b_2 = 3 items

b_3 = 80 ft walking distance

Productive time = $-0.52 + 0.57(1) + 0.31(3) + 0.010(80)$

Productive time = 1.8 min

Actual average productive time = 2.2 min

The predictive time required is 18 percent below the actual productive time observed.

System Cost Analysis

Complete cost records were not made available by Sanitary Disposal Company. Labor costs were obtained from employees and satellite vehicle operation costs were obtained from manufacturers literature.

Daily Crew Costs. The costs associated with a satellite vehicle waste collection crew are labor wages and fringe benefits, equipment operation and depreciation, and overhead. Equipment operation includes repairs and maintenance in addition to direct operating costs. The costs below are expressed in dollars per day.

Labor

2 - satellite vehicle operators at \$85/week + 15 percent fringe benefits	= \$39.10
1 - packer truck driver at \$95/week + fringe benefits	= 21.85
Total labor	= \$60.95

Satellite vehicle operation and depreciation

Operation

2 - satellite vehicles each at \$65 per month = \$ 5.98

Depreciation

2 - satellite vehicles, \$3590 new, 3 yr life = 9.20

\$15.18

Packer truck operation and depreciation

Operation

1 - 25 cu yd Garwood 700 at \$2,600/yr = \$10.00

Depreciation

1 - 25 cu yd Garwood 700, \$23,000 new, 5 yr life = 17.69

\$27.69

Overhead

Overhead cost was assumed to be 20 percent of all other costs. Overhead cost = 0.20(60.95 + 15.18 + 27.69) = 20.76

Total crew cost

The total daily satellite vehicle crew cost = \$124.58

Annual Collection Cost Per Dwelling Unit. The annual collection cost for the average dwelling unit observed during the field investigations in Knoxville for once weekly collection was determined by multiplying the crew efficiency by the crew cost rate. The crews observed during the study averaged 7.5 hr per day in the actual process of collection. Therefore the true crew cost rate was \$124.58 per 7.5 hr or approximately \$16.50 per hr.

The efficiency of the crew is the total number of dwelling units per hour serviced by the packer driver and the two satellite vehicle operators. The satellite vehicle operators averaged 12 dwelling units per 11.1 min or 65 dwelling units per hr. The packer driver services one dwelling unit per 2.2 min and collects 44 percent of his time for a total of 12 dwelling units per hr. The crew collects a total of 77 dwelling units per hr. The annual collection cost per dwelling unit is then:

$$\$16.50/\text{hr} \times 1\ \text{hr}/77\ \text{d.u.} \times 52\ \text{collections/d.u./hr} = \$11.00/\text{yr}$$

Collection Cost Per Ton. The residential waste generation rate for Knoxville was not able to be determined due to the unavailability of truck scales at the time of the study. Assuming the national residential waste generation rate of 3.0 lb/capita/day, the collection cost per ton was calculated. The amount of waste collected per hour by the average crew would be:

$$77\ \text{d.u./hr} \times 3.57\ \text{persons/d.u.} \times 3.0\ \text{lb/person/day} \times 7\ \text{days} = 5{,}750\ \text{lb/hr}$$

The collection cost per ton is then:

$$\$16.50/\text{hr} \times 1\ \text{hr}/5{,}750\ \text{lb} \times 2{,}000\ \text{lb/ton} \cong \$5.50/\text{ton}$$

Satellite Vehicle Collection vs. Conventional Collection. It is important to determine if the present satellite vehicle system used in Knoxville is more efficient and economical than a system using walking crews might be. An estimate of the efficiency and economy of a walking system was calculated using a regression model similar to the one developed for satellite collection vehicles.* The walking collector regression model is:

$$C = 0.18 - 0.12W_1 + 0.12W_2 + 0.24W_3 + 0.005W_4$$

---

*Appendix A

where C = productive time, in minutes, required to service W_1 dwelling units

W_1 = the number of dwelling units to be collected

W_2 = total number of items to be collected from W_1 dwelling units

W_3 = total number of trips to the truck while servicing W_1 dwelling units

W_4 = total distance, in feet, walked by collector while servicing W_1 dwelling units

The productive time required to service six dwelling units with the average characteristics observed during the field study was compared to the required time using satellite vehicles (Table D-3).

$W_1 = 6$ dwelling units

$W_2 = 2.5$ items/dwelling unit[*] x 6 dwelling units = 15 items

$W_3 = 1$ trip/3 items[+] x 15 items = 5 trips

$W_4 = [45 + 2.55 \text{ (average street to storage)}]\ X_1$[+]

$= [45 + 2.55(110)]\ 6 = 1{,}950$ ft

Substituting into the walking collector regression model:

$$C = 0.18 = 0.12(6) + 0.12(15) + 0.24(5) + 0.005(1{,}950) = 12.2 \text{ productive min}$$

Since the average walking collector is only 85 percent productive, the total time required becomes $\frac{12.2}{0.85}$ or 14.4 min.

The same six dwelling units were collected in a total time of 11.1 min by satellite vehicle. Therefore the average satellite

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[*] Table D-3

[+] Appendix A

vehicle operator is 30 percent more efficient than the average walking collector under these conditions.

The cost of a crew with two walking collectors and a packer truck driver in Knoxville amounts to \$108.07 per day. Converting to an actual workday of 7-1/2 hr increased the true crew cost to approximately \$14.50 per hr. Assuming that the packer driver would collect at the same rate as he presently does with the satellite vehicle crew, the total production of the crew would be:

$$2\left(\frac{6 \text{ dwelling units}}{14.4 \text{ min}} \times \frac{60 \text{ min}}{1 \text{ hr}}\right) + \frac{12 \text{ dwelling units}}{1 \text{ hr}} = 62 \text{ dwelling units/hr}$$

The cost per dwelling unit is then:

$$\$14.50/\text{hr} \times 1 \text{ hr}/62 \text{ dwelling units} \times 52 \text{ collections/yr} = \$12.00/\text{yr}$$

The collection service cost per dwelling unit for the satellite vehicle operation was \$11.00 per dwelling unit per year. Thus the conventional walking system cost would theoretically be 9 percent greater than the present satellite vehicle system.

Operational Comments

The collection routes observed during the field study were in very hilly areas with narrow, winding roads. The dwelling units were medium and high-income single family structures located on large lots with long, sloping driveways.

The customers of Sanitary Disposal Company were not considerate of the collectors in waste container type and storage point. Heavy-duty military style waste containers and 55-gal drums were quite common. Of the total items collected by the Trashmobile operators, 9.5 percent were 55-gal drums. The homeowners set the containers back from the road on collection day, instead of moving the containers forward to facilitate collection.

The wastes collected had a high percentage of food wastes causing maggots and malodors due to the once weekly collection during the hot and humid summer season. The high moisture content of the waste resulted in the production of a large amount of drainage with each compaction cycle of the packer. A drain in the packer truck hopper allowed moisture and maggots to drop onto the street on several occassions. Paper and plastic bags were not used to wrap the wastes, resulting in a loose, uncontainerized waste for collection. Sanitary Disposal Company is promoting twice weekly collection and use of plastic bags to combat these problems.

The average unloading time for the Trashmobiles, 0.9 min, was the lowest of all six areas studied. The Trashmobiles used in conjunction with 18 and 25 cu yd Garwood Load-Packer 700's with 1-1/2 cu yd hoppers required only one compaction cycle to accommodate an entire load. The sweeper blade of the packer scrapes the wastes from the hopper while it is raised in a vertical position. Spillage occurs when the Trashmobiles lack a rubber flap on the rear of the hopper, or when the packer truck hopper does not have a vertical metal extension welded to the lip of the hopper. Spillage was cleaned up from the pavement by the packer truck driver, using a broom and a dustpan after each unloading.

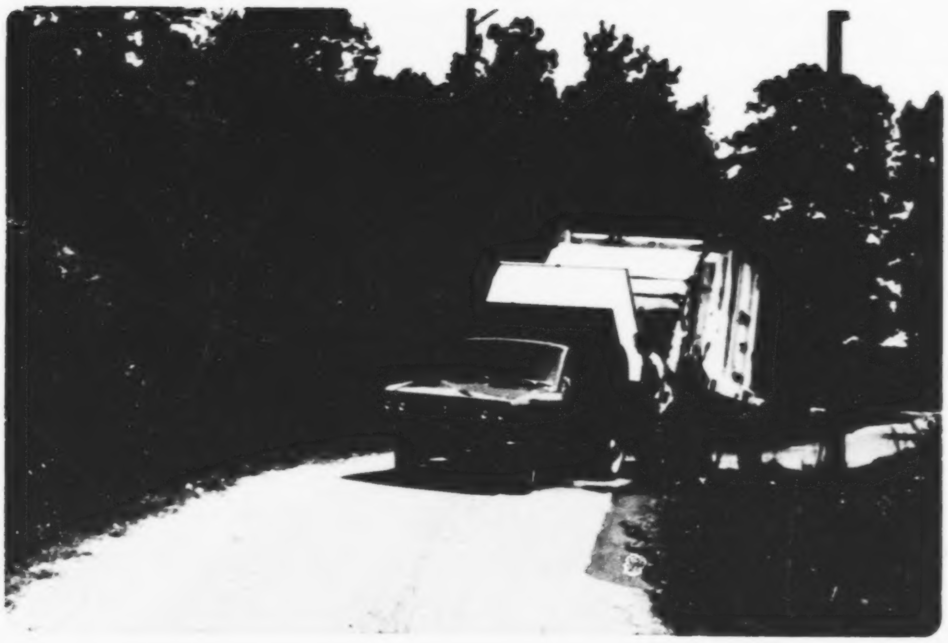

Figure D-1. Packer truck driver assisting unloading of satellite vehicle.

The packer truck drivers spent 43.3 percent of their time collecting. The drivers used 50-gal light-weight cardboard barrels to carry wastes from the dwelling unit storage point to the packer truck to prevent having to return homeowners' waste containers. The drivers were able to collect approximately 12 dwelling units during each hour on the route. The efficiency of the driver's collection was decreased, as 13.0 percent of the items collected were 55-gal drums. Approximately 20 percent of the driver's time was used to assist the Trashmobile operators in unloading and to direct them in their operation (Figure D-1).

The collection operations observed in Knoxville were very efficient. The Trashmobile operators provided the customers with responsible and careful service. Operators were especially careful to return waste containers to their original location and replace the covers. In addition, the operators did not overload their vehicles, and kept littering at a minimum. Wastes which did fall from the vehicles were always picked up by the operators. A little thoughtfulness on the part of the homeowners would result in an even more sanitary and efficient system than the operators are now providing.

APPENDIX E

MEDFORD, OREGON
FIELD STUDY, AUGUST 4-8, 1969

The City of Medford, Oregon is located in the flat agricultural Rogue Valley of southwestern Oregon. Medford has a moderate climate with marked seasonal characteristics. High temperatures in the summer average slightly below 90 degrees and the air is very dry. The lumber and wood products industry is the largest employer in the city as timber is brought into Medford for processing from the surrounding mountains. The total population of the city is estimated to be 30,500 (Table E-1).

City Sanitation Service Incorporated is franchised to collect residential solid wastes in Medford and surrounding areas of Jackson County. The company provides twice weekly collection to approximately 5,500 dwelling units in Medford. The collection charge is $33.00 per year for one 30 gal container per collection. For the 2,000 dwelling units in the outlying areas on once weekly collection the charge ranges from $18.00 to $30.00 per year.

The company began operating Cushman satellite vehicles in 1966 and has been very satisfied with their performance ever since. City Sanitation currently operates one crew with two satellite vehicles and four crews with one satellite vehicle and one walking collector. In addition, each crew has a packer truck and driver.

TABLE E-1

VITAL STATISTICS OF THE CITY OF MEDFORD, OREGON

Population[1]	30,500 (1/1/69)
Number of dwelling units[1]	10,400 (1/1/69)
Persons per dwelling unit	2.93
Land area[2]	11.3 sq mile
Population density	2,700 per sq mile
Dwelling unit density	920 per sq mile
Miles of street[2]	119.2
Dwelling units per street mile	90

[1] 1969 Rand-McNally Commercial Atlas and Marketing Guide

[2] Engineering Department, City of Medford

Field Study Analysis

During the 5 day study three satellite vehicle operators and two packer drivers were observed. The collection routes followed were on very flat terrain and the homes were predominantly medium and low income family dwelling units. Four days were spent on twice weekly collection routes and 1 day on a once weekly collection route.

Satellite Vehicle Collection Operational Analysis. Stepwise regression techniques were used on the data from each individual operator and from the three operators together (Table E-2). The regression model which best described the productive time for collection for the three satellite vehicle operators in Medford was:

$$Y_P = -3.02 + 0.40X_1 + 0.42X_2 + 0.01X_3 + 0.09X_4 + 3.50X_5$$

where Y_P = productive collection time per satellite vehicle load, in minutes

X_1 = number of dwelling units serviced per load

X_2 = number of items collected per load

X_3 = average distance the satellite vehicle goes up each dwelling unit driveway, in feet

X_4 = average distance from the satellite vehicle to storage point, in feet

X_5 = route distance of satellite vehicle, in miles

TABLE E-2

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS
MEDFORD, OREGON - AUGUST 4-8, 1969

Operator	Variable						R_2 Percent variation explained
	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway	X_4 Distance vehicle to storage	X_5 Route distance per load	X_0 Constant term	
MCD_1	*0.45	0.38	0.021	0.109	3.93	-5.11	95.5
MCD_2	*0.78	-	-	0.065	5.25	-2.32	91.2
MCD_3	0.38	0.46	0.009	0.076	*2.78	-1.47	67.3
Combined	0.40	*0.42	0.010	0.094	3.50	-3.02	80.7

*Most highly correlated variable to productive time.

This equation was able to explain 80.7 percent of the total variation in the data and the standard deviation of the residuals was 18.6 percent of the response mean, productive time. The F value of 63.5 and the similarity of coefficients for corresponding variables for each of the operators indicate that the five variables recorded were significant in explaining collection time. The variable most highly correlated to productive time in this model was X_2, the number of items per satellite vehicle load.

The utility and accuracy of the regression model was demonstrated by comparing it to the actual field results. For the example, average area and operational characteristics observed in Medford were used in the model (Table E-3). To account for unloading time and other time, the productive time must be divided by the fraction of productive time (Table E-4).

X_1 = 10 dwelling units per load

X_2 = 12 items per load

X_3 = 90 ft up driveway

X_4 = 20 ft from satellite vehicle to storage

X_5 = 0.80 miles route distance

Percent productive time = 82.2 percent

For the average satellite vehicle load:

$$\text{Productive time} = -3.02 + 0.41\,(10) + 0.42\,(12) + 0.010\,(90) + 0.094\,(20) + 3.50\,(0.80)$$

Productive time = 11.7 min

TABLE E-3

AVERAGE VALUES FOR SATELLITE VEHICLE COLLECTION VARIABLES
MEDFORD, OREGON - AUGUST 4-8, 1969

Operator	Satellite vehicle loads observed	Variable						
		X_1 Dwelling **units** serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway (ft)	X_4 Distance vehicle to storage (ft)	X_5 Route distance per load (mile)	D_{ss} Distance street to storage (ft)	Y Productive time per load (min)
MCD_1	25	10	11	80	20	0.65	100	10.0
MCD_2	20	12	13	70	30	0.65	90	11.9
MCD_3	37	9	11	110	20	0.95	120	12.5
Combined	82	10	12	90	20	0.80	110	11.6

TABLE E-4

SATELLITE VEHICLE OPERATOR ACTIVITY ANALYSIS
MEDFORD, OREGON - AUGUST 4-8, 1969

Operator	Total minutes observed	Percent of total time		
		Productive	Unloading	Other
MCD_1	385.6	82.1	11.5	6.4
MCD_2	357.6	83.3	10.6	6.1
MCD_3	570.3	81.5	12.0	6.5
Combined	1,313.5	82.2	11.4	6.4

Total elapsed time = $\frac{11.7}{.822}$ = 14.2 min.

Actual average productive time per load = 11.6 min

Actual elapsed time per load = $\frac{11.6 \text{ min}}{.822}$ = 14.1 min

The predicted productive time for the average load was within one percent of the actual productive time per load. This negligible difference demonstrates the accuracy of the satellite vehicle collection model for Medford.

Packer Truck Driver Operational Analysis. Regression analyses were made on the data recorded for the collection activity of the two packer truck drivers observed. Based on 236 data points the best equation for describing productive time for the two packer truck deivers in Medford was: (Table E-5)

$$T = -0.69 + 0.61b_1 + 0.31b_2 + 0.01b_3$$

where T = productive collection time required to service b_1 dwelling units between truck moves.

b_1 = number of dwelling units serviced between truck moves

b_2 = number of items collected from b_1 dwelling units

b_3 = average distance from truck to storage point, in feet

This equation explained 83.3 percent of the variation in the data and the standard deviation of the residuals was 26.9 percent of the response mean, productive time. The F value and the

TABLE E-5

PACKER TRUCK DRIVER COLLECTION MODEL COEFFICIENTS
MEDFORD, OREGON - AUGUST 4-8, 1969

Driver	Variables				R_2 Percent variation explained
	b_1 Number of dwelling units serviced between truck moves	b_2 Number of items collected	b_3 Average distance truck to storage	b_0 Constant term	
$MM20_1$	*0.60	0.44	0.009	-0.71	87.1
$MM20_2$	*0.59	0.16	0.010	-0.37	84.9
Combined	*0.61	0.31	0.011	-0.69	83.3

*Variable most highly correlated with productive time.

similarity of the coefficients for each variable in each regression model suggest that the three variables chosen are highly significant in describing productive time for collection. The most highly correlated variable to productive time was X_1, the number of dwelling units serviced between truck moves, in each of three regressions.

The regression model was tested to establish its accuracy in predicting productive collection time. The average values for the variables observed during the study were used in the example (Table E-6). The time spent on collection by the packer truck drivers was 45.8 percent of the total elapsed time (Table E-7).

b_1 = two dwelling units collected between truck moves

b_2 = two items

b_3 = 60 ft walking distance

Productive time = $- 0.69 - 0.61(2) + 0.31(2) + 0.01 (60)$

Productive time = 1.8 min

Actual productive time observed = 2.0 min

The predicted productive time required is 10 percent below the actual time.

System Cost Analysis

The daily costs associated with the satellite vehicle waste collection crews operated in Medford were obtained from City

TABLE E-6

AVERAGE VALUES FOR PACKER TRUCK DRIVER COLLECTION VARIABLES
MEDFORD, OREGON - AUGUST 4-8, 1969

Driver	Number of data points	Variables			
		b_1 Number of dwelling units serviced between truck moves	b_2 Number of items collected	b_3 Average distance truck to storage (ft)	Y_T Productive time (min)
$MM20_1$	120	2	3	80	2.3
$MM20_2$	116	2	2	50	1.6
Combined	236	2	2	60	2.0

TABLE E-7

PACKER TRUCK DRIVER ACTIVITY ANALYSIS
MEDFORD, OREGON - AUGUST 4-8, 1969

Driver	Date	Average miles per driving hour	Percent of total time				
			Assisting	Collecting	Driving	Waiting	Other
$MM20_1$	8/4	10.6	15.6	39.2	19.9	1.4	23.9
	8/7	9.5	12.0	59.7	13.5	2.3	12.5
	8/8	10.2	11.6	48.4	19.2	3.5	17.3
$MM20_2$	8/5	9.1	11.1	40.0	19.6	3.3	26.0
	8/6	8.5	17.1	35.4	19.8	5.0	22.7
Combined		9.5	13.3	45.8	18.4	3.2	19.3

Sanitation Service Inc. for the year 1968. The costs were for a three-man crew consisting of two satellite vehicles with operators, and a packer truck with a driver.

Daily Crew Costs. The costs associated with a satellite vehicle waste collection crew are labor wages and fringe benefits, equipment operation and depreciation, and overhead. Equipment operation costs include repairs and maintenance, in addition to direct operating costs. The costs given below are expressed in dollars per day.

Labor

2 - satellite vehicle operators at $24.25 per day
+ 15 percent fringe benefits = $55.78

1 - packer truck driver at $25.25 per day
+ 15 percent fringe benefits = 29.04

Total labor = $84.82

Satellite vehicle operation and depreciation

Operation

2 - satellite vehicles each at $725 per year = $ 5.60

Depreciation

2 - satellite vehicles, $2,300 new, 5 yr life = 3.52

Total operation and depreciation = $ 9.12

Packer truck operation and depreciation

Operation

1 - 20 cu yd Heil Collectomatic at $3,580 per year = $13.76

Depreciation

1 - 20 cu yd Heil Collectomatic, $16,000 new, 10 yr life = 6.15

Total operation and depreciation = $19.91

Overhead

Overhead cost was assumed to be 20 percent of all other costs

Overhead cost = 0.20 (84.82 + 9.12 + 19.91) = $22.77

Total crew cost

The total daily cost of the satellite vehicle crew described above = $136.62

Annual Collection Cost Per Dwelling Unit. The annual cost to service the average dwelling unit observed in Medford twice weekly was determined by multiplying the crew efficiency by the crew cost. The crews observed during the field investigation averaged 5.0 hr per day in the actual process of collection. Therefore the true crew cost was $136.62 per 5.0 hr or approximately $27.50 per hr. The efficiency of the crew is equal to the total number of dwelling units it can service per hour. The satellite vehicle operators each serviced 10 dwelling units per 14.1 min for a total of 86 dwelling units per hour. The packer drivers serviced two dwelling units per 2 min, but only collected 45.8 percent of each hour, or 27 dwelling units per hour. The total crew efficiency was 113 dwelling units per hour. The annual collection cost per dwelling unit for twice weekly collection is then:

$27.50/hr x 1 hr/113 d.u. x 104 collections/d.u./yr = $25.50/yr

Collection Cost Per Ton. The residential waste generation rate in Medford was determined by weighing the trucks which were followed during the study (Table E-8). The collection cost per ton was calculated by multiplying the crew cost per hour by the number of hours per ton. The amount of waste collected per hour by the average crew observed was:

113 d.u./hr x 3.1 lb/person x 2.93 persons/d.u. x 3.5 days = 3,600 lb/hr

The collection cost per ton is then:

$27.50/hr x 1 hr/3,600 lb x 2,000 lb/ton = $15.50/ton

Satellite Vehicle Collection vs. Conventional Collection

It is important to determine if the satellite vehicle waste collection system in Medford is more efficient and economical than a conventional walking collector system. An estimate of the efficiency and economy of a potential walking collector system can be calculated using the data obtained in the field study in a regression model for walking collectors (Appendix A). The regression model is:

TABLE E-8

RESIDENTIAL WASTE GENERATION
MEDFORD, OREGON - AUGUST 4-8, 1969

Date	Weight (lb)	Dwelling units	Lb/capita/day
8/5	18,090	580	2.7
8/7	15,310	466	3.7
Total	33,400	1,046	3.1

$$C = 0.18 - 0.12W_1 + 0.12W_2 + 0.24W_3 + 0.005W_4$$

where C = productive time, in minutes, required to service W_1 dwelling units

W_1 = the number of dwelling units to be collected

W_2 = total number of items to be collected from W_1 dwelling units

W_3 = total number of trips to the truck while servicing W_1 dwelling units

W_4 = total distance, in feet, walked by collector while servicing W_1 dwelling units

The productive time required to service 10 dwelling units with the average characteristics used in the satellite vehicle regression model calculations was calculated for walking collectors. A comparison of the two collection methods was made to reveal the more efficient and economic system.

W_1 = 10 dwelling units

W_2 = 1.2 items/dwelling unit* x 10 dwelling units = 12 items

W_3 = 1 trip/3 items+ x 12 items = 4 trips

$W_4 = \left[45 + 2.55 \text{ (average street to storage)}\right] W_1$+

$= \left[45 + 2.55 \text{ (110)}\right] 10 = 3,250 \text{ ft}$

---

*Table E-3

+Appendix A

Substituting into the walking collector regression model:

$$C = 0.18 - 0.12(10) + 0.12(12) + 0.24(4) + 0.005(3{,}250)$$

$$= 17.6 \text{ productive minutes}$$

Since the average walking collector is productive 85 percent of the time on the collection route, the total time required would be:

$$\frac{17.6}{0.85} \text{ or } 20.7 \text{ minutes}$$

The same 10 dwelling units can be serviced by a satellite vehicle in a total time of 14.1 min. Therefore the satellite vehicle operator is 46 percent more efficient than the walking collector under these average conditions.

The cost of a crew with two walking collectors and a packer driver in Medford is equal to the cost of a satellite vehicle crew minus the costs associated with the satellite vehicles.

$$136.62 = 1.2(9.12) = \$125.68/\text{day}$$

The Medford crews spend 5 hr per day on the collection route. The true crew cost is then approximately $25.00 per hr. Assuming that the packer truck driver would collect at the same rate as he does when working on a satellite vehicle crew, the crew efficiency would be:

$$2\left(\frac{10\ \text{dwelling units}}{20.7\ \text{min}}\ \frac{60\ \text{min}}{\text{hr}}\right) + \left(\frac{27\ \text{dwelling units}}{\text{hr}}\right) = \frac{85\ \text{dwelling units}}{\text{hr}}$$

The cost per dwelling unit is then:

$25.00/hr x 1 hr/85 dwelling units x 104 collections/yr = $30.50/yr

The collection service cost per dwelling unit for the satellite vehicle operation was $25.50 per year. The theoretical savings to be attributed to the use of the satellite vehicle system is $5.00 per dwelling unit per year. Use of walking collectors would theoretically increase collection costs 20 percent.

Operational Comments

City Sanitation Service, Inc. operates an efficient, sanitary and safe collection service in and around the City of Medford. The collectors have established an excellent relationship with the customers resulting in mutual benefaction. The customers maintain neat and convenient storage of wastes and the collectors reward them with clean and efficient collection.

The company's concern with safety was very impressive. The satellite vehicle operators were required to wear safety helmets when operating on heavily traveled streets and the vehicles were equipped with safety reflectors, extra turning signals and rear view mirrors. The operators made a practice of entering into traffic very cautiously when pulling away from the packer.

The satellite vehicle operators were very careful not to overload the vehicle hoppers. This practice prevented refuse from falling from the vehicles and littering the collection area. As an extra precaution, metal wing extensions were welded onto the sides of the vehicle hoppers to prevent refuse from blowing out while enroute to the packer or while the vehicle was unloading.

The packer trucks were radio-equipped for relaying information on extras and misses to the crews from the company office. Customer requests and complaints are thus rectified in minimum time.

All of the satellite vehicle operators and packer truck drivers used aluminum tote barrels for transferring wastes from the storage point to their respective vehicles. These cans have a rounded shoulder rest, a one side handle, and a capacity of approximately 40 gal. The collectors were very satisfied with this type of tote barrel.

The packer trucks used in conjunction with the satellite vehicles were Heil Collectomatic Mark III's with a capacity of 20 yd^3. The 1½ cu yd rear hoppers were not adequate for accommodating the 1¼ cu yd of waste in the satellite vehicle hoppers. Therefore, two compaction cycles of 12 sec each were required to empty each satellite vehicle load of waste. The satellite vehicles partially unloaded, lowered their hoppers, pulled away for the compaction cycle, backed up to the packer hopper and repeated the process of unloading. The average unloading time was 1.8 min. A packer with a 2 or 3 cu yd rear hopper could reduce the unloading time to approximately 1 min per satellite vehicle load.

The primary advantage which the collectors in Medford enjoy is the low number of items per dwelling unit. Almost all of the dwelling units served had only one item to be collected because of the company service charge policy. Also, 87 percent of the items collected during the field study were standard containers. If the items per dwelling unit were increased to the study average of 2.6, the regression model predicts that a 37 percent decrease in collection efficiency would result. This illustrates the effectiveness of the company policy which minimizes items by charging for extras.

APPENDIX F

PASADENA, CALIFORNIA
FIELD STUDY, JULY 28 - AUGUST 1, 1969

The City of Pasadena is located in the center of Los Angeles County, separated from the City of Los Angeles by the San Rafael Hills. These hills in the northwest section of Pasadena have been developed into modern high income housing areas. The major portion of the city has flat terrain with older low to medium income housing. The population of 125,000 (Table F-1) has a large percentage of people over age 65 resulting in a low growth rate in recent years.

Residential solid waste collection and disposal is the responsibility of the Engineering-Street Department of the City of Pasadena. Prior to 1963 the City provided conventional collection using five man crews with dolly carts and 70 gallon fiberglass containers in conjunction with 16 yd^3 packer trucks. At that time the City operated 16 routes for combustible refuse and four routes for non-combustible refuse. Heavy accumulation of refuse due to once per week collection and increasing incidence of back injuries caused the City to try using the Westcoaster, a three-wheeled satellite collection vehicle of 1 1/3 cu yd capacity in June, 1963. The success of these satellite vehicles in reducing costs and increasing efficiency resulted in subsequent purchases until the entire system had been converted. The Department reduced the number of routes from 15 in 1963 to 13 in 1969 with a corresponding reduction in men from 125 to 80. The 16 yd^3 packers have now been replaced by specially built

TABLE F-1

DESCRIPTION OF PASADENA, CALIFORNIA

Population	125,000 (1/1/69)*
Dwelling units	47,200 (1/1/69)*
Persons per dwelling unit	2.65
Land area	22.7 miles^{2}+
Population density	5,510 persons/miles^{2}
Dwelling density	2,080 $\text{dwellings/mile}^{2}$
Miles of roads	330 miles+
Dwelling units per street mile	140/mile
(estimated for hilly area)	50/mile

*From 1969 Rand-McNally Commercial Atlas and Marketing Guide

+From Director of Sanitary Service, City of Pasadena

50 yd^3 packers requiring only two trips to the Scholl Canyon Landfill per day. The one route in the hilly, western sector uses a 25 yd^3 packer for the required maneuverability. The City now has 40 scooters with 32 to 36 operating on 13 routes daily. The crews have a packer driver, two or three collectors with satellite vehicles, plus one or two men with containers on dolly carts.

Field Study Analysis

The field study was conducted from July 28 through 31. A crew of one packer driver, three satellite vehicle operators and one walking man was accompanied in the hilly, western sector of Pasadena for the first 2 days. The last two days were spent in the flatter central area with a crew of one packer driver, two satellite vehicle operators and two walking collectors with containers on dolly carts. Only two satellite vehicle operators and the packer driver were observed in each crew during the study. Due to the distinct characteristics of the two areas and the two types of packer trucks used, the crews were analyzed individually. A total of 337 data points were obtained on six different satellite vehicle operators in Pasadena. The two packer drivers observed did not do enough collection to develop a productive collection time regression model.

Satellite Vehicle Collection Operational Analysis. Stepwise regression analyses were conducted on the data for each individual satellite vehicle operator and ultimately on the data from all the operators combined. The regression model which best described productive collection time for the six satellite vehicle operators observed in Pasadena was: (Table F-2)

$$Y_P = -1.22 + 0.63X_1 + 0.20X_2 + 0.007X_3 + 0.107X_4 + 5.04X_5$$

where Y_P = productive time required per satellite vehicle load

X_1 = number of dwelling units serviced per load

X_2 = number of items collected per load

X_3 = average distance satellite vehicle up driveway, in feet

X_4 = average distance from satellite vehicle to storage, in feet

X_5 = route distance of satellite vehicle, in miles

This equation was able to explain 84.5 percent of the total variation in the data and the standard deviation of the residuals was 25.9 percent of the response mean, productive time. As the F value, 271.1 was very high, it can be said that the model, which

TABLE F-2

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS
PASADENA, CALIFORNIA - JULY 28-31, 1969

Collector	Variable						R_2 Percent variation explained
	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway	X_4 Distance vehicle to storage	X_5 Route distance per load	X_0 Constant term	
PWW_1	0.44	0.28	0.003	0.109	*4.73	-1.19	86.6
PWW_2	*1.24	0.20	0.006	0.134	3.36	-0.58	91.1
PWC_1	*0.51	0.18	-	-0.035	5.97	-0.01	73.6
PWC_2	-	-	0.019	-	*12.47	-0.61	85.0
PWC_3	*0.73	0.16	0.007	0.042	3.83	-1.14	74.5
PWC_4	*1.11	-	0.008	-	-	1.16	90.5
Combined	0.63	0.20	0.007	0.107	*5.04	-1.22	84.5

*Variable most highly correlated with productive collection time.

was developed using five independent variables, is significant. The variable most highly correlated to productive time in this model was the route distance of the satellite vehicle. There was a large difference in route distances between operators in the west and the central sections (Table F-3). Western area operators traveled 0.50 miles per load versus 0.15 miles by the central area operators.

The utility and accuracy of the productive time regression model was established by comparing it to the productive time actually observed during the field study. The flat and hilly areas were discussed individually due to their distinct characteristics. To predict the time required to complete one satellite vehicle load the average variable values were substituted into the regression model (Table F-3). The fraction productive time was used to convert the productive time to elapsed time required (Table F-4). The following values were used in the model:

	Hilly	Flat
X_1 = dwelling units per load	= 3	3
X_2 = items per load	= 10	10
X_3 = distance vehicle up driveway	= 120 ft	100 ft
X_4 = distance vehicle to storage	= 10 ft	0
X_5 = route distance of satellite vehicle	= 0.50	0.15
Percent productive time	= 82.3%	80.2%

TABLE F-3

AVERAGE VALUES FOR SATELLITE VEHICLE COLLECTION VARIABLES PASADENA, CALIFORNIA - JULY 28-31, 1969

Operator	Satellite vehicle loads observed	Variable						
		X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway (ft)	X_4 Distance vehicle to storage (ft)	X_5 Route distance per load (mile)	D_{ss} Distance street to storage (ft)	Y_P Productive time per load (min)
PWW_1	77	3	10	100	10	0.45	90	6.8
PWW_2	55	3	11	140	10	0.60	130	9.5
Total hilly	132	3	10	120	10	0.50	110	7.9
PWC_1	81	3	9	90	0	0.20	80	4.1
PWC_2	11	2	8	90	0	0.15	90	2.8
PWC_3	100	3	11	110	0	0.15	110	4.1
PWC_4	13	3	11	100	0	0.20	100	5.4
Total flat	205	3	10	100	0	0.15	100	4.1

TABLE F-4

SATELLITE VEHICLE OPERATOR ACTIVITY ANALYSIS
PASADENA, CALIFORNIA - JULY 28-31, 1969

Scooter collector	Total minutes observed	Percent of total time		
		Productive	Unloading	Other
PWW_1	650.0	80.7	14.6	4.7
PWW_2	624.4	83.7	13.1	3.2
Total hilly	1,274.5	82.3	13.7	4.0
PWC_1	411.9	81.2	15.9	2.8
PWC_2	47.1	66.5	18.3	15.2
PWC_3	512.7	80.8	13.7	5.5
PWC_4	86.2	81.8	14.0	4.2
Total flat	1,057.9	80.2	14.9	4.8

Hilly. Substituting the values into the regression model yields:

$$\text{Productive time} = -\,1.22 + 0.63(3) + 0.20(10) + 0.007(120) + 0.107(10) + 5.04(0.50) = 7.1 \text{ min}$$

$$\text{Elapsed time} = \frac{7.1}{.823} = 8.6 \text{ min}$$

The actual average productive time per load observed during the study period was 7.9 min (Table F-3). The regression model estimate is 10 percent low.

Flat. Using the data for the central area the model becomes:

$$\text{Productive time} = -\,1.22 + 0.63(3) + 0.20(10) + 0.007(100) + 0.107(0) + 5.04(0.15) = 4.1 \text{ min}$$

$$\text{Elapsed time} = \frac{4.1}{.802} = 5.1 \text{ min}$$

The productive time per load during the study averaged 4.1 min (Table F-3). The regression model estimate agrees with the actual productive time observed perfectly.

Packer Drivers. The time spent on collection by the two packer truck drivers observed was negligible (Table F-5). Most of the driver's time was spent assisting the satellite vehicle operators and walking collectors when they returned to the truck to unload (Table F-5).

TABLE F-5

PACKER TRUCK DRIVER ACTIVITY ANALYSIS
PASADENA, CALIFORNIA - JULY 28-31, 1969

Driver	Date	Average miles per driving hour	Percent of total time				
			Assisting	Collecting	Driving	Waiting	Other
PP25	7/28	11.5	42.8	0.5	18.2	27.9	10.7
	7/29	8.4	43.1	4.6	29.0	20.2	3.2
P650	7/30	6.3	57.3	2.5	14.2	19.3	6.7
	7/31	6.0	56.9	1.8	16.6	22.1	2.5

System Cost Analysis

The costs associated with satellite vehicle waste collection were obtained from the Director of Sanitation of the City of Pasadena. In order to allow meaningful comparison with other satellite vehicle crews, the walking collectors were not included in the time and cost analyses.

Daily Crew Costs. The costs of a satellite vehicle waste collection crew are labor, equipment operation and depreciation, and overhead. Equipment costs in Pasadena are determined by the City's Transportation Division, which rents the collection vehicles to the Engineering Street Department. The rental charges include operation, maintenance, depreciation and overhead. The following costs are expressed in dollars per day.

Labor.

2 - satellite vehicle operators each @$562/mo. + 44 percent for fringe benefits and overhead	= $89.60
1 - sanitation truck driver @$606/mo. + 44 percent for fringe benefits and overhead	= $48.31
Total Labor	$137.91

Satellite Vehicles.

2 - satellite vehicles each @$210/mo. = $19.08
(Rental includes operation, maintenance depreciation and overhead)

Packer Truck. A 25 cu yd Pak-Mor packer truck was used in the hilly collection area and Gaskin-Built 50 cu yd packer trucks were used in the rest of the city.

25 cu yd packer @$680 rental per month (Rental includes operation, maintenance, depreciation and overhead)	= $30.90
50 cu yd packer @$850 rental per month (Rental includes operation, maintenance, depreciation and overhead)	= $38.63
Total daily crew cost	
Crew working in hills	=$187.89
Crew working in flat area	=$195.62

Annual Collection Cost per Dwelling Unit. The annual collection cost for the average dwelling units observed in the hilly and flat sections of Pasadena can be determined by multiplying the crew efficiency by crew cost rate.

Hilly Area. The crew observed in the hilly area spent an average of 5.5 hr per day in the actual process of collection. The true crew cost would be \$187.89 per 5.5 hr or approximately \$34.00 per hr. The efficiency of the crew is the total number of dwelling units which it can service in an hour. This crew averaged six dwelling units per 9.5 min during the study for a crew efficiency of 38 dwelling units per hour. The annual collection cost per dwelling unit is then:

$$\$34.00/\text{hr} \times 1\ \text{hr}/38\ \text{d.u.} \times 52\ \text{collections/d.u./yr} \cong \$46.00/\text{yr}$$

Flat Area. In the flat area the crew observed spent 5.0 hr per day in the actual process of collection. The true cost for this crew is then \$195.62 per 5.0 hr or approximately \$39.00 per hr. The crew efficiency was six dwelling units per 5.1 min or 71 dwelling units per hr. The annual collection cost per dwelling unit in this area is:

$$\$39.00/\text{hr} \times 1\ \text{hr}/71\ \text{d.u.} \times 52\ \text{collections/d.u./yr} \cong \$28.50$$

Collection Cost per Ton. The residential waste generation rate for both sections of Pasadena was determined by weighing the trucks followed during the study (Table F-6). From the waste

TABLE F-6

RESIDENTIAL WASTE GENERATION, PASADENA, CALIFORNIA JULY 28-31, 1969

Date	Section	Weight (lb)	Number of services	Lb/capita/day
7/28	West	24,820	273	4.9
7/29	West	24,580	336	3.9
Total	West	49,400	609	4.4
7/30	Central	30,240	558	2.9
7/31	Central	28,260	503	3.0
Total	Central	58,500	1,061	3.0

generation rate and the crew cost and efficiency, the collection cost per ton for both areas of Pasadena may be established.

Hilly Area. The amount of waste per hour collected by the crew observed in this area was:

38 d.u./hr x 2.65 persons/d.u. x 4.4 lb/person/day x 7 days ≅ 3,100 lb/hr

The collection cost per ton is:

$34.00/hr x 1 hr/3,100 lb x 2,000 lb/ton ≅ $22.00/ton

Flat Area. The amount of waste per hour collected by the crew observed in the flat area was:

71 d.u./hr x 2.65 persons/d.u. x 3.0 lb/person/day x 7 days = 3,950 lb/hr

The collection cost per ton is:

$39.00/hr x 1 hr/3,950 lb x 2,000 lb/ton = $19.50 /ton

Satellite Vehicle Collection vs. Conventional Collection

It is important to determine if the satellite vehicle waste collection system operated in Pasadena is more efficient and economical than a conventional walking collector ystem. The efficiency and economy to be expected if walking men were to replace the satellite vehicles in Pasadena can be calculated using the data obtained in the field study in a regression model for walking collectors. The regression model is:

$$C = 0.18 - 0.12W_1 + 0.12W_2 + 0.24W_3 + 0.005W_4$$

where C = productive time in minutes to service W_1 dwelling units

W_1 = the number of dwelling units to be serviced

W_2 = total number of items to be collected from W_1 dwelling units

W_3 = total number of round trips to the truck by the collector while servicing W_1 dwelling units

W_4 = total distance walked by collector while servicing W_1 dwelling units, in feet

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*Appendix A

Hilly Area

The distinct hilly characteristics of the western section of Pasadena warrant separate estimates of the time to service three dwelling units there and in the rest of the city. The distance which the collectors would walk in the hilly area is greater than for the normal situation since there are very few lawns and walking collectors must use the home dwelling unit driveways.

W_1 = three dwelling units

W_2 = 3.3 items per dwelling unit + x 3 dwelling units = 10 items

W_3 = 1 trip per dwelling unit

$W_4 = 2(X_3 + X_4)\ W_1$ + route distance = 2(110+20)3+600=1380

+ Table F-3

Substituting into the walking collector regression model:

$$Y_P = 0.18 - 0.12(3) + 0.12(10) + 0.24(3) + 0.005(1,380) = 8.6 \text{ productive min}$$

Since the average walking collector is productive 85 percent of the total time on the route, the total time required to service three dwelling units would be $\frac{8.6}{0.85}$, or 10.1 min.

The satellite vehicle operators observed in Pasadena used 9.5 min to service three dwelling units with identical characteristics. Therefore, satellite vehicles servicing this area would theoretically be 6 percent more efficient.

The cost of a crew with two walking collectors, a packer driver and a packer truck operating in West Pasadena is $168.81 per day. Since the crew spends 5.5 hr on the collection route each day, the true crew cost is approximately $30.50 per hr. The two walking collectors service a total of six dwelling units each 10.1 min. The annual collection cost per dwelling unit is then:

$$\$30.50/\text{hr} \times \frac{10.1 \text{ min}}{6 \text{ dwelling units}} \times 1 \text{ hr}/60 \text{ min} \times 52 \text{ collections/yr} = \$44.50$$

The annual cost per dwelling unit for satellite vehicle collection in this area was $46.50.

Theoretically, use of walking collectors in this area would reduce the present cost of collection by 4 percent.

Central.

W_1 = three dwelling units

W_2 = 3.3 items per dwelling unit[*] x 3 dwelling units = 10 items

W_3 = 1 trip per dwelling unit

W_4 = 45 + 2.55 (average distance street to storage) X_1[+]

= 45 + 2.55 (100) 3 = 900

Substituting into the walking collector regression model:

$$Y = 0.18 - 0.12(3) + 0.12(10) + 0.24(3.0) + 0.005(900) = 6.24 \text{ productive min}$$

Since the average walking collector is productive 85 percent of the total time on the route, the total time required to service three dwelling units would be $\frac{6.24}{0.85}$ or 7.3 min.

The satellite vehicle operators in Pasadena required an average of 5.1 min to service three dwelling units with identical characteristics. Therefore, the satellite vehicle collection method is theoretically 43 percent more efficient than walking collectors in this area.

The cost of a crew consisting of two walking collectors, a packer truck driver and a packer truck, operating in the flat sections of Pasadena is $176.54 per day. Since the crews spend 5.0 hr on the collection route per day, the true cost per hour is

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[*] Table D-3

[+] Appendix A

approximately \$35.50 per hr. The two walking collectors service a total of six dwelling units each 7.3 min and the driver does not collect. The annual collection cost per dwelling unit is then:

$$\$35.50/\text{hr} \times \frac{7.3 \text{ min}}{6 \text{ dwelling units}} \times 1 \text{ hr}/60 \text{ min} \times 52 \text{ collections/yr} = \$37.50/\text{yr}$$

The collection annual cost per dwelling unit for satellite vehicle service in this area is \$28.50 per year. Theoretically, use of satellite vehicles in this area of Pasadena provides collection at a rate 24 percent below that for conventional walking collection.

The cost estimates in Pasadena for the two distinct types of collection areas illustrate the fact that there is no set answer as to which type of system is the most economical, until all factors have been evaluated and used in the regression models.

General Comments and Conclusions

Hilly Area. No major inefficiencies in the satellite vehicle collection operations were observed during the study of the five-man crew in the hilly, western section of Pasadena. However, it may be possible to reduce the crew to four men, as the one walking collector was able to collect from only 91 dwelling units in two days while the scooters collected an average of 168 dwelling units a piece.

The amount of waste and number of items collected at each residence was very high due to amount of garden wastes collected. From the container characterization study conducted during the field investigation, the amount of garden wastes was estimated at 30 percent (Table F-7). The low number of items per satellite vehicle load is due to the size of the standard container used in Pasadena. Homeowners used 30-gal cans instead of the customary 20 gal container used in most communities. Therefore satellite vehicles were only able to carry 10 items per load instead of 15, the average for other cities studied.

The operators were particularly careful not to overload their vehicles. Speeds were kept at a minimum when the vehicles were full and blowing paper and other refuse was always retrieved by the operator when dropped from a load. The satellite vehicles and packer truck had to contend with very heavy traffic in the mornings, but managed to maneuver safely and deliberately. The packer truck had a train bell as a safety feature which worked automatically when backing up.

The satellite vehicles required an average of 1.3 min to unload into a 25 yd^3 Pak-Mor packer with a 3 yd hopper. The large hopper allowed the satellite vehicles to dump an entire load with only one compaction cycle.

Flat Area. The major difference between this five-man crew and the crew observed in the hilly section was in the care exercised during collection. These operators overloaded their vehicles, neglected some items at certain services and failed to retrieve wastes which fell from the vehicles. In addition, the vehicles were driven too fast when loaded, resulting in heavy littering of yards and roads. The crew was not as well coordinated as the crew in the hilly area and operators duplicated dwelling units frequently.

The number of items at each dwelling unit was similar to the western area but the amount of waste at each residence was less. Garden wastes constituted 30 percent of the wastes collected (Table F-7).

The average unloading time for the satellite vehicles was 0.8 in this crew. This short unloading time was accomplished by use of a front overhead loading Gaskin-built 50 yd^3 packer. The satellite vehicles dump into an unobstructed large bin at the front of the packer which was more accessible than a packer with a rear hopper. The bin was then hoisted over the cab and emptied into the packer after the satellite vehicle has left the packer truck.

TABLE F-7

PASADENA CONTAINER CHARACTERIZATION
JULY 28-31, 1969

Date	Total items	Percent of total items			
		Standard container non-garden	Standard container garden	Miscellaneous non-garden	Miscellaneous garden
7/28	614	78.2	(garden wastes not recorded)	21.8	
7/29	665	47.1	20.0	23.1	9.8
7/30	1,155	48.5	21.7	19.2	10.6
7/31	933	67.6	(garden wastes not recorded)	32.4	

APPENDIX G

WAUKESHA COUNTY, WISCONSIN

FIELD STUDY, JULY 8-11, 1969

Waukesha County is located in the flat southeastern section of Wisconsin directly west of Milwaukee County. The County has benefited from westward expansion of the City of Milwaukee, producing one of the highest county population growth rates in the United States in the 1960's. The population has increased from 158,249 in 1960 to an estimated 212,000 in 1969. This suburb of Milwaukee is characterized by upper middle class homes in large housing developments built within the last ten years to meet the needs of commuters not wishing to live in the city. These homes are located on small lots and are close to the street.

Sanitary Disposal Service, Inc. provides once weekly waste collection service to approximately 50 to 60 percent of the population of Waukesha County on a private or contract basis. The company began using Cushman scooters in October 1966 in an attempt to increase collection efficiency. Sanitary Disposal Service currently operates 22 Cushman scooters in two man crews with two scooters per crew. The scooters are transported to the routes in pairs on trailers hauled behind the packer trucks (Figure G-1). The packer driver operates a scooter in addition to the packer truck during collection by attaching his satellite vehicle to the packer truck when moving it.

Figure G-1. Satellite vehicles with hauling trailer.

The use of plastic bags for waste storage has been recently initiated by Sanitary Disposal to further reduce collection time. The cost of these bags to the customer is $.05 per bag and approximately 15 percent of the customers were using plastic bags at the time of the study.

Field Study Analysis

The field investigation was conducted July 8 through 11 in the City of Brookfield and the Village of Elm Grove in Waukesha County. One crew was observed for the four day period. The area in which the crew operated was very flat with modern upper-middle class homes located on small lots with short driveways. The housing density of this area was about 40 houses per mile (Table G-1), but since Sanitary Disposal only has about 75 percent of the residences as customers, the effective density was reduced to 30 houses per mile. The company requires that the storage area be easily accessible to the scooters in order to reduce walking distance to an average of 10 ft at each dwelling unit.

Stepwise regression analyses were made on the data for both collectors individually and combined. The average variable values and the mathematical models for both drivers were very similar (Tables G-2, G-3). From this and the percent of the variation covered it can be concluded that the variables recorded are very significant and therefore reliable in predicting productive time per satellite vehicle load. The regression model which best described productive collection time for the 173 satellite vehicle loads observed in Waukesha County was:

TABLE G-1

COMBINED STATISTICS
CITY OF BROOKFIELD AND VILLAGE OF ELM GROVE
WAUKESHA COUNTY, WISCONSIN

Population*	39,800 (est. 1969
Dwelling unit*	9,500 (est. 1969)
Persons per dwelling unit	4.18
Land area*	29 sq miles
Population density	1,370 persons per mile^2
Housing density	330 homes per mile^2
Miles of street*	233 miles
Houses per street mile	40

*From Village Manager of Elm Grove and City of Brookfield Department of Public Works.

$$Y_P = -\ 0.89 + 0.54\ X_1 + 0.15\ X_2 + 0.011\ X_3 + 0.047\ X_4 + 2.93\ X_5$$

where Y_P = Productive collection time per satellite vehicle load, in minutes

X_1 = Number of dwelling units serviced per load

X_2 = Number of items collected per load

X_3 = Average distance satellite vehicle travels up driveway of each dwelling unit, in feet

X_4 = Average distance from satellite vehicle to storage at each dwelling unit, in feet

X_5 = Route distance of satellite vehicle per load, in miles

This equation was able to explain 83.0 percent of the total variation in the data and the standard deviation of the residuals was 20.0 percent of the response mean, productive time. The F value of 163.5 indicates that these five variables are significant in explaining productive time. The route distance per load of the satellite vehicle was the most highly correlated variable to productive time in this equation. This means that the variations in productive collection time per satellite collection vehicle load were best accounted for by the corresponding variation in route distance traveled by the vehicle.

To illustrate the utility and accuracy of the regression model developed, it was compared to actual field observation values. Using the average variable values, the productive time

TABLE G-2

SATELLITE VEHICLE COLLECTION MODEL COEFFICIENTS
WAUKESHA COUNTY, WISCONSIN - JULY 8-11, 1969

Operator	Variable						R_2 Percent variation explained
	X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway	X_4 Distance vehicle to storage	X_5 Route distance per load	X_0 Constant term	
WCD_1	0.42	0.17	0.007	0.026	*3.05	-0.24	85.3
WCD_2	*0.78	0.10	0.014	0.047	2.59	-1.56	84.0
Combined	0.54	0.15	0.011	0.047	*2.93	-0.89	83.0

*Variable most highly correlated to productive time.

TABLE G-3

AVERAGE VALUES OF SATELLITE VEHICLE COLLECTION VARIABLES, WAUKESHA COUNTY, WISCONSIN - JULY 8-11, 1969

Driver	Satellite vehicle loads observed	Variable						
		X_1 Dwelling units serviced per load	X_2 Items collected per load	X_3 Distance vehicle up driveway (ft)	X_4 Distance vehicle to storage (ft)	X_5 Route distance per load (mile)	D_{ss} Distance street to storage (ft)	Y_ρ Productive time per load (min)
WCD_1	102	5	22	70	10	0.60	70	8.0
WCD_2	71	5	22	70	0	0.60	70	7.4
Combined	173	5	22	70	10	0.60	70	7.7

required to make one trip with the satellite vehicle was predicted (Table G-3).

Unloading and other time were accounted for by dividing the productive time by the fraction of productive time (Table G-4) to yield total elapsed time required.

X_1 = Dwelling units per load = 5

X_2 = Items per load = 22

X_3 = Average distance vehicle goes up driveway = 70 ft

X_4 = Average distance from vehicle to storage = 10 ft

X_5 = Route distance of vehicle per load = 0.60 miles

Percent productive time substituting into the model; = 77.5 percent

$$\text{Productive time} = -\,0.89 + 0.54(5) + 0.15(22) + 0.011(70) + 0.047(10) + 2.93(0.60)$$

$$\text{Productive time} = 8.1 \text{ min per load}$$

$$\text{Total elapsed time} = \frac{\text{productive time}}{.775} = \frac{8.1}{.775} = 10.5 \text{ min per load}$$

The predicted productive time of 8.1 min per load is 5 percent above the average time observed, 7.7 min per load, during the field study (Table G-2). Therefore, the regression model is very accurate in describing productive time required per satellite vehicle load.

TABLE G-4

SATELLITE COLLECTION VEHICLE OPERATOR ACTIVITY ANALYSIS WAUKESHA COUNTY, WISCONSIN, JULY 8-11, 1969

Operator	Total minutes observed	Percent of total time			
		Productive	Unloading	Driving packer	Other
WCD_1	1,117.4	80.7	17.6	0.0	1.7
WCD_2	706.5	72.7	15.2	5.9	6.2
Combined	1,823.9	77.5	16.6	2.2	3.7

System Cost Analysis

The costs for the average satellite vehicle collection crew in Waukesha County, Wisconsin were obtained from the owner of Sanitary Disposal Service, Inc. Two man crews were used in Waukesha County, but were equivalent to three man crews in other areas. The cost calculations and comparisons are based on the assumption of crew equivalency.

Daily Crew Costs. The daily cost of a satellite vehicle collection crew consists of labor, satellite vehicle operation and depreciation, packer truck operation and depreciation, and overhead. The costs are given in dollars per day.

Labor

2 - satellite vehicle operators at $180/wk = $ 72.00

Satellite vehicle operation and depreciation

Operation

2 - satellite vehicles each at $1,000/yr = 7.70

Depreciation

2 - satellite vehicles, $3,000 new, 2 yr life = 11.54

Total operation and depreciation = $19.24

Packer truck operation and depreciation

Operation

1 - 25 cu yd Heil at $2,500/yr = $ 9.61

Depreciation

1 - 25 cu yd Heil, $15,000 new, 4 yr life = 14.40

Total operation and depreciation = $24.01

Overhead

Overhead cost was unable to be obtained from Sanitary Disposal Service, Inc. and therefore was estimated at 20 percent of all other costs.

Overhead cost = 0.20(72.00 + 19.24 + 24.01) = $ 23.05

Total crew cost

The total daily crew cost is $138.30

Annual Collection Cost per Dwelling Unit. The annual collection cost for the average dwelling unit observed in Waukesha County for once weekly collection was determined by multiplying the crew efficiency by the crew cost rate. The crew observed during the field investigation worked approximately 7.0 hr per day in the actual process of collection. The true crew cost rate is then $138.30/day x 1 day/7.0 hr or approximately $20.00 per collection hour. The crew efficiency was 10 dwelling units per 9.9 min or 61 dwelling units per hr. The annual collection cost per dwelling unit for once weekly collection is then:

$$\$20.00/\text{hr} \times 1\ \text{hr}/61\ \text{d.u.} \times 52\ \text{collections/d.u./yr} \cong \$17.00$$

Collection Cost per Ton. During the field investigation, five truck loads of waste were weighed to determine the residential solid waste generation rate in Waukesha County (Table G-5). The collection cost per ton was calculated using this generation rate. The amount of waste collected per hour by the crew would be:

61 d.u./hr x 4.18 persons/d.u. x 2.6 lb/capita/day x 7 days = 4,600 lb/hr

Multiplying by the crew cost per hour produces the collection cost per ton.

$$\$20.00/\text{hr} \times 1\ \text{hr}/4{,}600\ \text{lb} \times 2{,}000\ \text{lb/ton} \cong \$8.50/\text{ton}$$

Satellite Vehicle Collection vs. Conventional Collection. Productive time requirements and costs for conventional walking collection were estimated and compared to satellite vehicle collection using a regression model similar to the one developed for satellite vehicles. The regression model for walking collection is:

$$C = 0.18 - 0.12W_1 + 0.12W_2 + 0.24W_3 + 0.005W_4$$

where C = Productive time in minutes to service W_1 dwelling units

W_1 = The number of dwelling units to be collected

W_2 = Total number of items to be collected from W_1 dwelling units

W_3 = Total number of trips to truck while servicing W_1 dwelling units

W_4 = Total distance walked by collector while servicing W_1 dwelling units, in feet

The average housing characteristics used in the satellite vehicle calculations were used to calculate the productive time required for one walking collector to service five dwelling units.

TABLE G-5

RESIDENTIAL SOLID WASTE GENERATION
WAUKESHA COUNTY, WISCONSIN
JULY 8-10, 1969

Date	Weight (lb)	Dwelling units serviced	lb/capita/day
7/8	12,350	154	2.7
	10,350	164	2.2
7/9	14,250	161	3.0
	6,100	88	2.4
7/10	10,550	143	2.5
Total	53,600	710	2.6

The results were then compared with satellite vehicle collection to determine the most efficient method for Waukesha County. The average values for Waukesha County were:

W_1 = five dwelling units

W_2 = 4.4 items/dwelling unit[*] x 5 dwelling units = 22 items

W_3 = 1 trip/3 items[+] x 22 items = 7.33 trips

$$W_4 = \left[45 + 2.55\ (\text{average street to storage distance})\right] W_1{}^{+}$$

$$= \left[45 + 2.55\ (70)\right]\ 5 = 1{,}120\ \text{ft}$$

Substituting these values into the regression model,

$$Y_P = 0.18 - 0.12(5) + 0.12(22) + 0.24(7.33) + 0.005(1{,}120)$$

$$= 9.6\ \text{min of productive time}$$

Since the average walking collector who also drives the crew truck is productive 80 percent of the time while on the collection route (Appendix A), the total time required to service five dwelling units becomes $\frac{9.6}{0.80}$ or 12.0 min. The satellite vehicle operator serviced an equivalent number of dwelling units in a total time of 9.9 min. Therefore, satellite vehicle waste collection in Waukesha County is theoretically 21 percent more efficient than the alternate method of waste collection by walking collectors.

The cost of a walking collection crew in Waukesha County would be $115.20 per day. Since the crew spends approximately 7 hr per day on the collection route the true cost per hour is

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[*] Appendix A

[+] Table G

approximately $16.50. The two man crew can collect a total of 10 dwelling units per 12 min or an equivalent of 50 dwelling units per hr. The annual collection cost per dwelling unit is then:

$16.50/hr x 1 hr/50 dwelling units x 52 collections/yr = $17.00

The annual cost per dwelling unit for satellite vehicle collection was also $17.00. Thus the two methods are theoretically equal on the basis of economics alone.

Operational Comments

The unique concept used by Sanitary Disposal Service, Inc. of having the packer driver also operate a satellite vehicle is very efficient. Driving the packer truck occupied a maximum of only 6 percent of one man's time. This leaves 94 percent of the operator's time to be available for productive work instead of waiting at the truck. The time required to attach or detach the satellite vehicle from the packer was only 0.3 min. The only disadvantage to leaving the packer truck unmanned and running is the danger of children innocently or intentionally tampering with it.

The operators in the area observed were benefited in their operation by the accessability to the waste storage point. Very short driveways averaging 70 ft in length with little or no walking distance from the vehicle to the storage point increased crew efficiency significantly.

Customers were very thoughtful in their choice of a storage point and the collectors were seldom required to ring doorbells to ask people to unlock garages, the most common storage area.

The average number of items collected per dwelling unit, 4.6, was extremely high. This value was nearly twice the average value for the other five areas studied, due to garden wastes which constituted approximately 50 percent of the total wastes. The amount of waste collected in the winter would thus be reduced significantly. Approximately 40 percent of the items were not in standard containers.. Most of the wastes collected were containerized in paper and plastic bags, increasing transportability by the satellite vehicles. Approximately 15 percent of the items collected were plastic bags. The operators carried a supply of plastic bags in their vehicles and delivered them to customers upon request.

The satellite vehicle operators observed used an excessive amount of time unloading the wastes into the packer truck. The high average unloading time of 1.7 min was due to several reasons. The hopper on the 25 cu yd Heil Collectomatic Mark III has only a 1.5 cu yd capacity requiring 2 to 3 compaction cycles to accommodate the waste from the satellite vehicles. This problem was enhanced by the consistent overloading of the satellite vehicles by their operators (Figure G-2). The 1-1/4 cu yd satellite vehicle hoppers were usually heaped up to about 2 cu yd before returning to the packer truck. The operators averaged 22 items per load compared to an average of 15 items per load for the six study areas. Operators had to unload the satellite vehicles carefully and slowly to avoid spilling wastes onto the pavement from the overloaded vehicles.

Reducing the number of items per load and use of a packer with a 3 cu yd hopper could decrease unloading time significantly. In addition, the installation of a rubber flap on the back of the satellite vehicle hopper could reduce the amount of waste spillage and attendant cleaning up time.

The Company reported very little trouble due to winter snowfall. No adverse effects on normal operations were experienced until there was more than 2 in. of snow on the ground.

Figure G-2. Overloaded satellite vehicle